A MAGNETIC DRUM SURFACE GAUGE

T. T. FOSSUM

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A MAGNETIC DRUM SURFACE GUAGE

T. T. FOSSUM

A MAGNETIC DRUM SURFACE GAUGE

by

T. T. Fossum
Lieutenant, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
IN
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United States Naval Postgraduate School

PREFACE

The research for and preparation of this thesis was done at the Advanced Electronics Laboratory, Research and Development Laboratories, Hughes Aircraft Company, Culver City, California, during the latter half of the academic year 1953-1954.

For improvement in magnetic drum design, a method of measuring variations on drum surfaces with a sensitivity of 25 to 50 microinches is desirable. Also, the method must be capable of dynamic, as well as static measurements. This thesis is the report of the design, construction, and testing of such an instrument.

The writer would like to express his appreciation to Mr. C. A. Deutschle for his suggestion of the topic, guidance, encouragement, and proof reading.

The writer is also indebted to Mr. D. L. Smith for assistance in construction and testing, to Mr. W. Fernholtz for mechanical design of the probe and shield, to the Machine Shop, Advanced Electronics Laboratory, for construction of the probe and shield, and to Mrs. Ruth H. Morton for the typing.

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I. SUMMARY

The objective of the research for this thesis was the design, construction, and testing of an instrument to measure surface variations of magnetic drum rotors.

The method used was to have a probe in the shape of a flat plate mounted above the drum to form a parallel plate condenser with the drum surface. Variations on the drum surface cause variations in probe capacitance. This condenser tunes an oscillator, the output of which is fed to an FM I.F. amplifier. The output of the FM discriminator is fed to a meter circuit.

The Magnetic Drum Surface Gauge is capable of measurement of variations of 2.0 microinches when used with an oscilloscope, and 4.0 microinches when used with a 50 microampere meter.

II. INTRODUCTION

Present methods of measurement of magnetic drum rotors by use of dial gauges are limited to an accuracy of one-tenth of a mil and cannot be used dynamically. For future development in magnetic drum design, an instrument that will measure static and/or dynamic variations in a drum surface, with a sensitivity of 25 to 50 micro inches, is desirable.

The idea for such an instrument was originally conceived in the Radar Laboratory, Hughes Aircraft Company, for a special purpose. This thesis represents essentially a complete new design to meet the radically different specifications.

The instrument should be capable of dynamic as well as static measurement in order to be able to determine the magnitude of various dynamic effects separately from the static condition. The stability of the instrument should be such that it can be used in vibration, environmental, and quality testing and still maintain an accuracy of 5 to 10 percent. The resolution of the instrument should be such that the area measured approximates as far as possible the effective area of a drum reading and writing head. It is desirable that the instrument be linear in order that the output can be read directly in distance without having to resort to calibration curves.

It is to be noted that the use of the instrument is not restricted to drum surface measurement, but can be used to measure variations on any metallic surface.

III. THEORY

Figure 1 is an over-all block diagram of the instrument. A probe in the shape of a flat disc is mounted above the drum in the window in the reading and writing head holder. The drum surface forms one plate of a parallel plate condenser and the flat circular disc probe is the other plate. As the capacitance of a simple parallel plate condenser varies inversely with the distance between the plates, any variation on the drum surface causes a change in the capacitance of the probe, if the drum is moved under the probe. This varying capacitance is used to tune an oscillator with a center frequency of 10.7 megacycles.

A small portion of the energy of the oscillator is coupled to the first stage of an intermediate frequency amplifier and discriminator. Variations on the drum surface cause changes in the frequency of the oscillator. Variations in frequency about the center frequency of the intermediate frequency amplifier give an output from the FM discriminator which is proportional to the distance of the probe from the drum.

The output of the discriminator is fed through a cathode follower to an oscilloscope for dynamic measurements and to a DC microammeter for static measurements.

1. The Oscillator

(a) Basic considerations

(1) Oscillator stability

The frequency of oscillation of any type of oscillator is affected by conditions existing within the tube. Variations in the supply voltage affect the magnitudes of the plate and grid resistances and the tube transconductance. Use of regulated plate and cathode voltages and

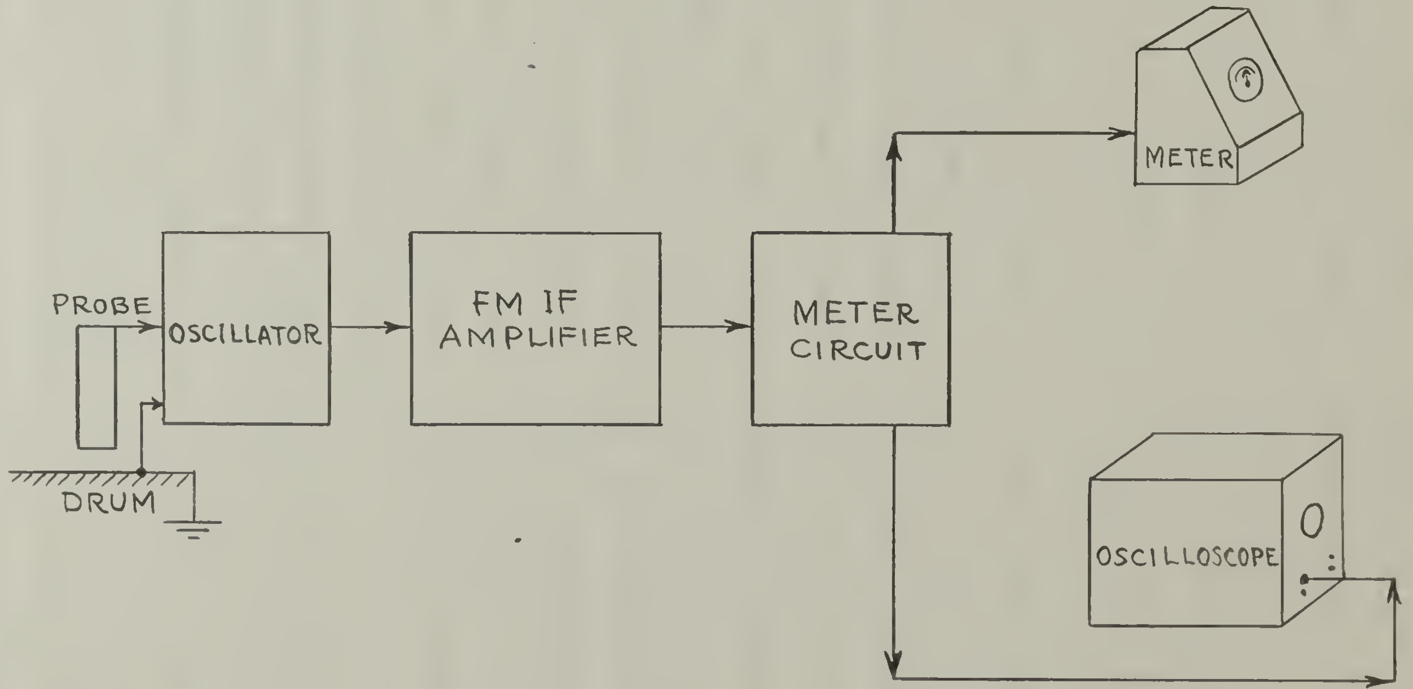

FIGURE 1

OVERALL BLOCK DIAGRAM

of high resistance grid leak bias with a grid leak resistor bypass condenser minimizes voltage variation effects. Effects of plate resistance variation may be reduced by adding a high impedance in the plate circuit in the form of a high resistance or a blocking condenser so that the percentage variation due to changes in r_p will be small.

A low L to C ratio in the oscillator tank circuit is desirable since the electrostatic energy stored in the tank condenser should be high in comparison to that stored in the tube capacitances.

The use of a pentode electron coupled oscillator will reduce the oscillator frequency variations due to variations in the plate supply voltage. It is experimentally observed that a small increase in screen voltage results in a small increase in frequency, but that a small increase in plate voltage causes a small decrease in frequency. These separate effects can be utilized to nullify each other by deriving the screen voltage from a voltage divider connected across the plate voltage supply and adjusting the screen tap by trial until the frequency does not change with variation in the supply voltage. Also, the effect of load variations, i.e. frequency pulling, is reduced by isolation of the load by means of the electron coupled oscillator. The use of a resistive load or a tuned tank also reduces frequency pulling.

Oscillation frequency changes can result from thermal effects which affect frequency-critical physical properties such as dimensions and resistivity, resulting in changes of L, C, and R of the network. The use of a high circuit Q and the highest possible ratio of tube transconductance to variations in tube capacitances will decrease the effect of temperature change. Mounting of the tube external to the enclosure for the coil and condenser will protect the oscillator tank from heat dissipation of the

tube. Adequate ventilation and minimum power input to the oscillator will help reduce thermal effects while in extreme cases zero temperature coefficient components or temperature compensating components may be used.

Mechanical effects from vibration and shock also cause changes in component values and tube coefficients. Use of short, stiff leads and cushioning of the oscillator mounting will reduce the effects of vibration. Potting components in order to hold them rigidly in place can also be accomplished.

(2) The Transistor Considerations

As the junction transistor works on the principle of an impedance transformation and has a current gain of less than one, its use as an oscillator is limited to the lower frequencies. Therefore, the point contact transistor was considered for use in the oscillator circuit. The advantages of the transistor are low power consumption and, therefore, low heat dissipation, small size, and less susceptibility to vibration than a vacuum tube.

On the other hand the current gain (α) drops off rapidly above approximately 100°F. and therefore the point contact transistor cannot be used in environmental testing. Also, due to the critical spacing between the emitter and collector, it is difficult to procure a transistor that will oscillate in the 4.5 - 10.7 megacycle range. The transistor is affected by frequency pulling and the emitter voltage is critical; thus a voltage regulation problem is present.

It was decided that a transistor oscillator is impractical for this application due to the difficulty of procurement, the effect of loading, the low gain available, and the voltage regulation required.

(3) Location of Oscillator

For environmental testing, five feet of cable are necessary to connect a probe to the instrument chassis. General usage coaxial cable has a capacitance of 7 to 13 uuf. per foot; the expected range of probe capacitance is 0.35 to 0.06 uuf. Therefore, if the probe is connected directly to the tank circuit with coaxial cable the sensitivity of the oscillator is relatively low because of the possible 35 to 65 uuf. of cable capacitance in parallel with that of the probe. The stability of the oscillator is also lower than otherwise since the variations in cable capacitance due to twisting and temperature changes directly affect the oscillator frequency.

One method of isolating the cable from the oscillator tank is to mount the complete oscillator circuit on the drum head holder. This subjects the oscillator to mechanical vibrations and size and weight become important factors in the design. Therefore, the coil and the chassis of the oscillator must be rigid and the tube of the ruggedized subminiature type shielded from the coil. This approach subjects the oscillator to extreme temperature variations during environmental testing. However, thermal effects can be reduced by use of a rigid coil and zero temperature coefficient components or temperature compensating components.

Another method which essentially isolates the cable is to mount the probe and coil on the head holder and to use a remotely tuned Clapp (series tuned Colpitts) oscillator, connecting the probe and coil to the feedback condensers with the cable. The cable capacitance becomes part of the feedback condensers and thereby has negligible effect on the sensitivity of the oscillator. As the frequency of oscillation is dependent almost entirely on the series capacitance, changes in the cable and tube capacitances have negligible effect on the oscillator frequency. Also, the

oscillator coil is not susceptible to the thermal effects due to the heat dissipation of the tube and the tube is not subject to vibration and temperature variations in environmental testing. Because of these advantages, it was decided to use this approach in the actual design.

(4) Sensitivity

The higher the oscillator frequency the greater is the frequency shift for a given capacitance change along with a corresponding percentage decrease in stability, for a given design. On the other hand, the lower the I.F. frequency, the higher the discriminator sensitivity. In an effort to combine these two different characteristics, the use of a high frequency oscillator and beat frequency oscillator to allow use of a narrow band discriminator, 20 kc bandwidth at 456 kc, was considered.

Experimentation with oscillators operating at 10.7 mc indicated that an oscillator with a sensitivity of 500 kc per uuf. change was possible. With the characteristic of a 10.7 mc I.F. amplifier being 1 mv = 16 cycles, it was determined that a complete system working at a center frequency of 10.7 mc would be satisfactory.

On the basis of the above considerations, the decision was made to use a series tuned Colpitts electron coupled oscillator operating at 10.7 mc, with screen voltage derived from a voltage divider connected across the plate voltage supply. A decision was also made to mount only the probe and coil on the head holder and to connect the coil to the instrument chassis with coaxial cable. The method of mounting the probe and coil should allow the use of the instrument on different size drums and the absolute distance of the probe from the drum should be adjustable.

(b) The Series Tuned Colpitts Oscillator

(1) The Oscillator

The basic series tuned Colpitts circuit is shown in Figure 2. Dashed connections indicate connecting cable. The oscillator is tuned by varying the effective inductance of the oscillator tank with variable condenser C_1.

The condition for oscillations to occur is that $R_c = -g_m X_2 X_3$, Figure 3 is the graph $C_{2,3}$ versus g_m for various coil resistances. The value of the feedback condensers is limited by the resistance of the coil at 10.7 mc. Lowering the value of the feedback condensers will increase the frequency of oscillation but will reduce the stability of the oscillator.

The frequency of oscillation is given by

$$f = \frac{1}{2\pi (L_1 C_1)^{\frac{1}{2}}} \left[1 + \frac{C_1}{C_2} + \frac{C_1}{C_3} \right]^{\frac{1}{2}}$$

Using an inductor of 15 uh. and total feedback condensers of 285 uuf. the graph of the value of C_1 versus frequency is plotted in Figure 4. This curve shows that the theoretical sensitivity of the oscillator is 400 kc per uuf. in the frequency range of the instrument.

The feedback condensers C_2 and C_3 include the cable capacitance, the grid-cathode and the plate-cathode capacitances. Changes in frequency due to changes in the cable capacitance and tube capacitances are negligible. For example, using a series condenser of 13.5 uuf. and an increase in the tube and cable capacitance of 10 uuf. the resultant frequency change is 7600 cycles. Since pentodes generally have input and output capacitances of 3 to 7 uuf. and the stray capacitances are 2 to 3 uuf. in good design, the total added capacity across the feedback condensers is about 6 uuf. The capacitance of the cable is constant at room temperature (See Figure 12). Allowing a five percent variation in added capacitance due to temperature changes the resultant change in frequency will be only 228

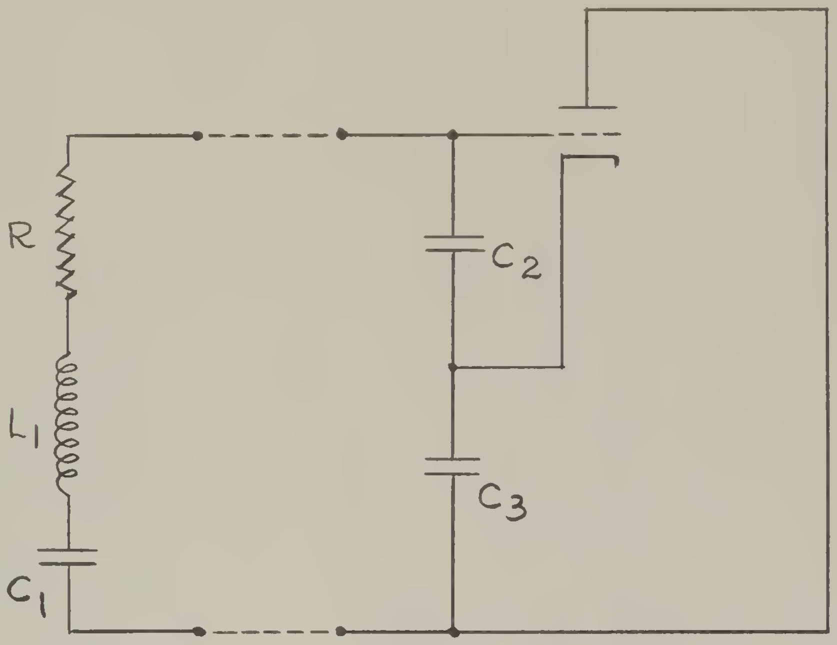

FIGURE 2

BASIC CLAPP CIRCUIT

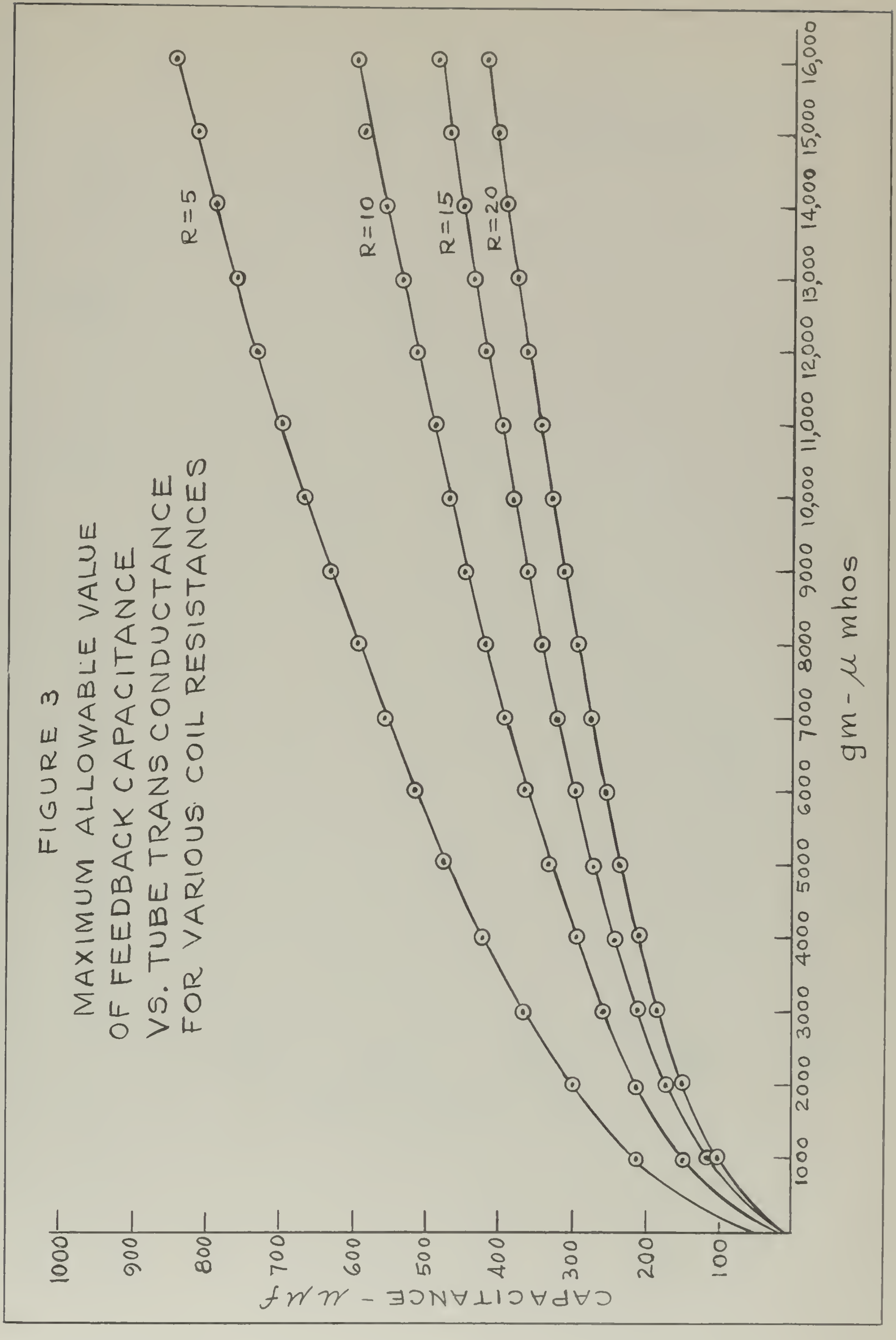

FIGURE 3

MAXIMUM ALLOWABLE VALUE OF FEEDBACK CAPACITANCE VS. TUBE TRANSCONDUCTANCE FOR VARIOUS COIL RESISTANCES

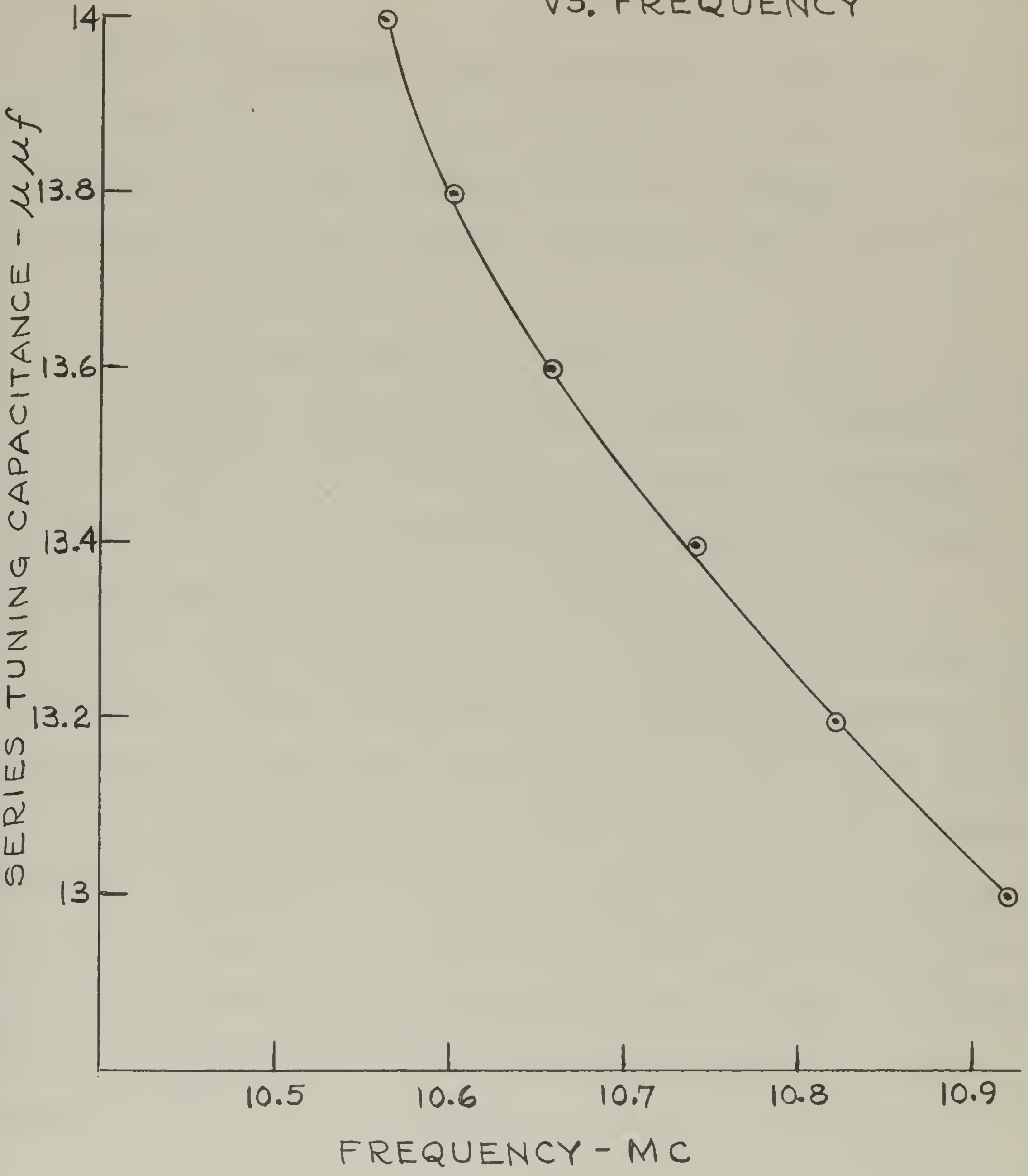

FIGURE 4
SERIES TUNING CAPACITANCE
VS. FREQUENCY

cycles. Figure 5 is a graph of the change of the value of the feedback condensers vs. frequency. This shows that effect of the feedback condensers is very small until they approach the value of the series tuned condenser.

Therefore, by making the tuning capacitance, C_1, small and the feedback condensers large, the expression under the square root sign is very nearly unity. The frequency becomes relatively independent of the feedback condensers and mainly dependent on the series tuned circuit L_1C_1.

(2) The Coil

For high stability the oscillator coil must not be susceptible to temperature changes or vibrations. One method of making a stable coil is to groove the coil form and stretch the wire on tightly; then coat with ceramic and bake. A disadvantage of this method is an increase in coil self-capacitance.

A second method would be to plate the coil by first flashing the form with a silver base and then plating it with copper to the thickness of "wire" desired. Grooves would then be cut in the copper surface through to the coil form to form the "wire" turns. Plating the coil on polyethylene linen base and bakelite forms was attempted, but the plating would not hold to the form while grooving with a lathe. This was due to the fact that the bakelite and polyethylene were not very porous. The form should be of a porous type of material, such as ceramic, to allow the plating to hold.

A variation of this method is to groove the form first to the depth desired and then fill the grooves by silver flashing and copper plating. The form is then turned down on a lathe until the ridges of the grooves show. This method has the disadvantages of increasing the coil self-

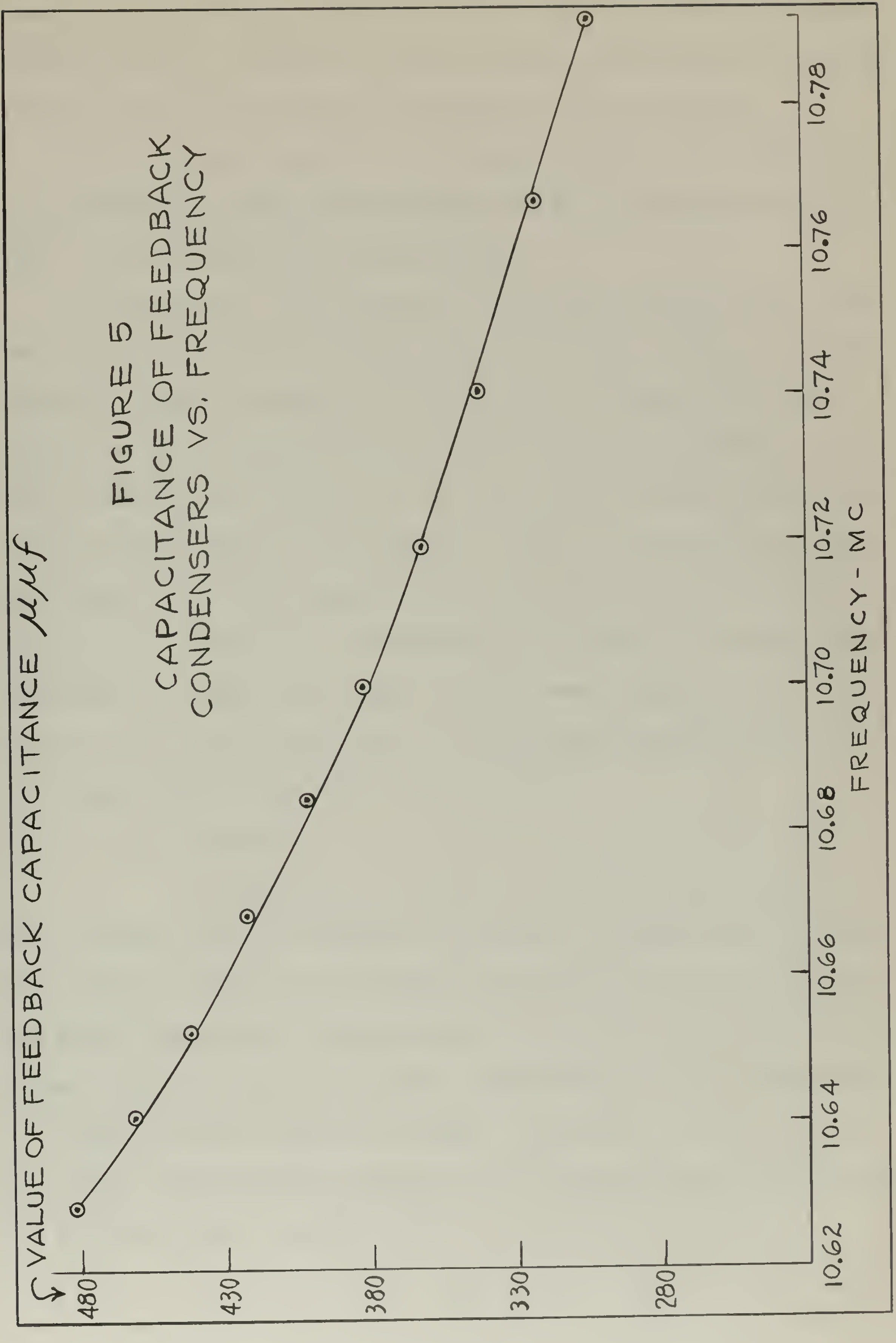

FIGURE 5
CAPACITANCE OF FEEDBACK
CONDENSERS VS. FREQUENCY

capacitance by putting a dielectric between the turns and the process of plating grooves is difficult. There is a good possibility of air pockets forming in the plate which would increase the coil resistance.

Due to the lack of time it was decided to groove a 7/8" bakelite form and wind the coil tightly. The coil would then be covered with Q-max cement to hold the turns in a rigid position.

The sensitivity of the oscillator is limited by the coil self capacitance. This is determined by the spacing between the turns, the distance between the turns and ground (the shield), and the length of the coil. Filling the space between the turns increases the self-capacitance due to the introduction of a dielectric. As the inductive branch of the oscillator must remain inductive throughout the range of frequencies of oscillation desired, the series tuning condenser can never be lower in value than the coil self capacitance. This means that the coil self resonant frequency must be appreciably higher than the center frequency of the oscillator. The coil self capacitance also introduces dielectric losses at the higher frequencies, thereby lowering the Q.

(3) The Probe

The possibility of making the probe of such a shape as to give a linear change in frequency with change in distance was considered. The oscillator frequency is inversely proportional to the square root of the series capacitance. The capacitance of the probe is inversely proportional to the distance from the drum. Therefore $k_1 f^2 = k_3 d$ (see Appendix I).

Due to the small area of the probe, construction of several probes of a special shape would be difficult and the advantage of interchangeability of probes without separate calibration curves would be lost.

The frequency sensitivity of an experimental oscillator was checked at 10.7 mc. Decreasing the series capacitance 1 uuf. gave a frequency change of 580 kc. Increasing the series capacitance 1 uuf. gave a frequency change of 444 kc.

$$\% \text{ Difference } f_1 = \frac{580}{1070} = 54.2\%$$

$$\% \text{ Difference } f = \frac{444}{1070} = 41.6\%$$

$$\text{Error} = \frac{54.2 - 41.6}{2} = \pm 6.3\% \text{ from a linear relationship.}$$

This is in agreement with the theoretical frequency variation (see Figure 4). Since the expected range of probe capacitance is 0.35 to 0.06 uuf. the response is essentially linear as shown in Figure 4.

If the Frequency vs. Distance curve (Figure 8) is broken up into several short lengths, and straight lines between the points, the frequency is essentially proportional to the distance over each length, but with a different sensitivity.

From the above considerations it was determined that the advantages gained by shaping the probe would be negligible.

One of the specifications of the probe face is that it should approximate the effective area of the reading and writing heads. The size of the reading and writing head flux gap is 2 by 75 mils. The effective area on the drum surface is somewhat larger due to fringing flux. The most simple method of construction for the probe is to use a cylindrical rod. It was felt that a rod 40 mils in diameter would be satisfactory, having about twice the resolution of the head in one coordinate, and about 1/30th the resolution in the other coordinate. Areawise, the probe has about 1/8th the resolution of a drum head.

With a probe diameter of 40 mils, the instrument will respond to sin-

usoidal surface variations with periods down to 0.2 inches or 5 bits per inch with a 5 percent loss in the indicated amplitude. The surface velocity of a 4-inch drum is 1670 inches per second; therefore, the instrument should have a frequency response that is flat to 20 kc.

Even though the amplitude response of the probe will be lower at shorter wave lengths than 0.2 inches, it can, however, be used with wave lengths appreciably shorter than 0.2 inches. It is only necessary to measure the period of the defects and apply the resolution correction factor ($E \propto \frac{\lambda}{\pi D} \sin \frac{\pi D}{\lambda}$), where λ is the measured period and D is the diameter of the probe) to the measured amplitude. For example, if the wave length is 0.09 inches, the response will be 70 percent of that at 0.2 inches (see Appendix II).

If a single defect appears on an otherwise smooth drum surface, the instrument will indicate a single pulse of constant amplitude with a length that is 40 mils plus the length of the defect.

The probe face and drum surface do not form a true parallel plate condenser throughout the range of operation of the instrument. Capacitance varies directly as the area of the plates and inversely as the distance between them. Referring to Figure 6, for parallel plate theory to be applicable, D, the diameter of the probe must be much greater than d, the distance between the plates.

The inverse relation, $\frac{1}{d}$, holds with small error in the region $0 \leq d \leq \frac{D}{10}$. For a probe 40 mils in diameter the inverse law applies for probe to drum spacings of 0 to 4 mils.

Also, when d approaches a, the clearance of the shield from the probe fringing from the side of the probe has an effect on the capacitance. If the clearance, a, is filled with insulation which has a dielectric constant,

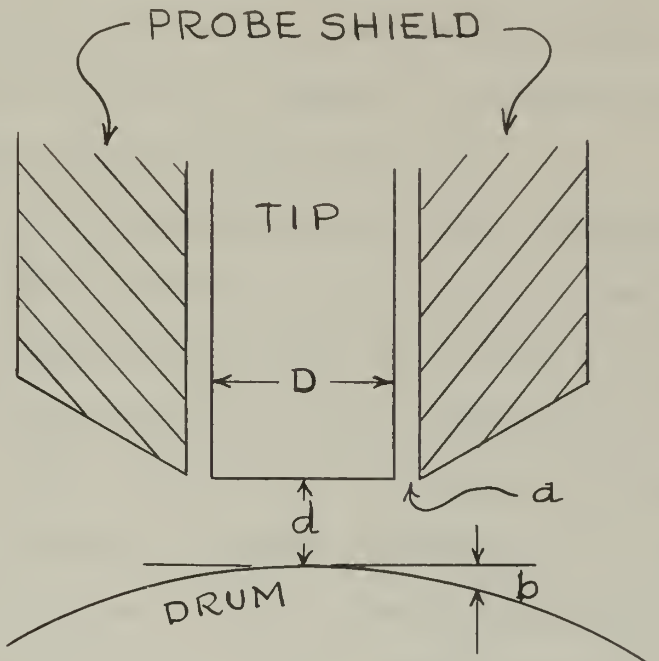

FIGURE 6

PROBE SHIELD, TIP AND DRUM

K, the effective clearance a_e is $\frac{a}{K}$. Therefore, the effective spacing can be decreased by increasing the dielectric constant of the insulation used. For a probe to drum spacing of less than 10 a_e the inverse relation does not apply.

Vinylite cement has a dielectric constant of about 10. If the shield clearnace is one mil and the probe is insulated with Vinylite cement, the effective clearance is 0.1 mils. Therefore, the inverse law applies for probe to drum surface spacings greater than 1 mil.

The curvature of the drum surface also causes a departure from parallel plate theory. Since the probe is mounted with its face perpendicular to a line drawn through its vertical axis and the drum rotor axis, the edges of the probe are further away from the drum surface than the center. For a 40 mil diameter probe, the increase in the probe to drum spacing, b, is .1 mil for a drum 4 inches in diameter. Therefore, for a 40 mil diameter probe, the average increase in probe to drum spacing caused by curvature is approximately 5% and 1.25% at 4 mils. Beyond 4 mils the effect of curvature increases due to fringing on one hand and decreases due to greater distance from the drum on the other. This theoretical discussion of the curvature effect is for two dimensions. It was felt a more rigorous discussion treating the drum as a cylinder rather than a sphere was unnecessary as the effect would be even less than that estimated above.

From the above considerations it was determined that a cylindrical probe, 40 mils in diameter, with a shield clearance of 1 mil filled with Vinylite cement would satisfactorily follow the inverse relation for probe to drum surface distances from 1 to 4 mils.

Figure 7 is the Capacitance versus Distance curve for a 40 mil diameter probe. Figure 8, the curve of Frequency versus Distance, was calculated by combining Figure 7 with the Tuning Capacitance versus Frequency

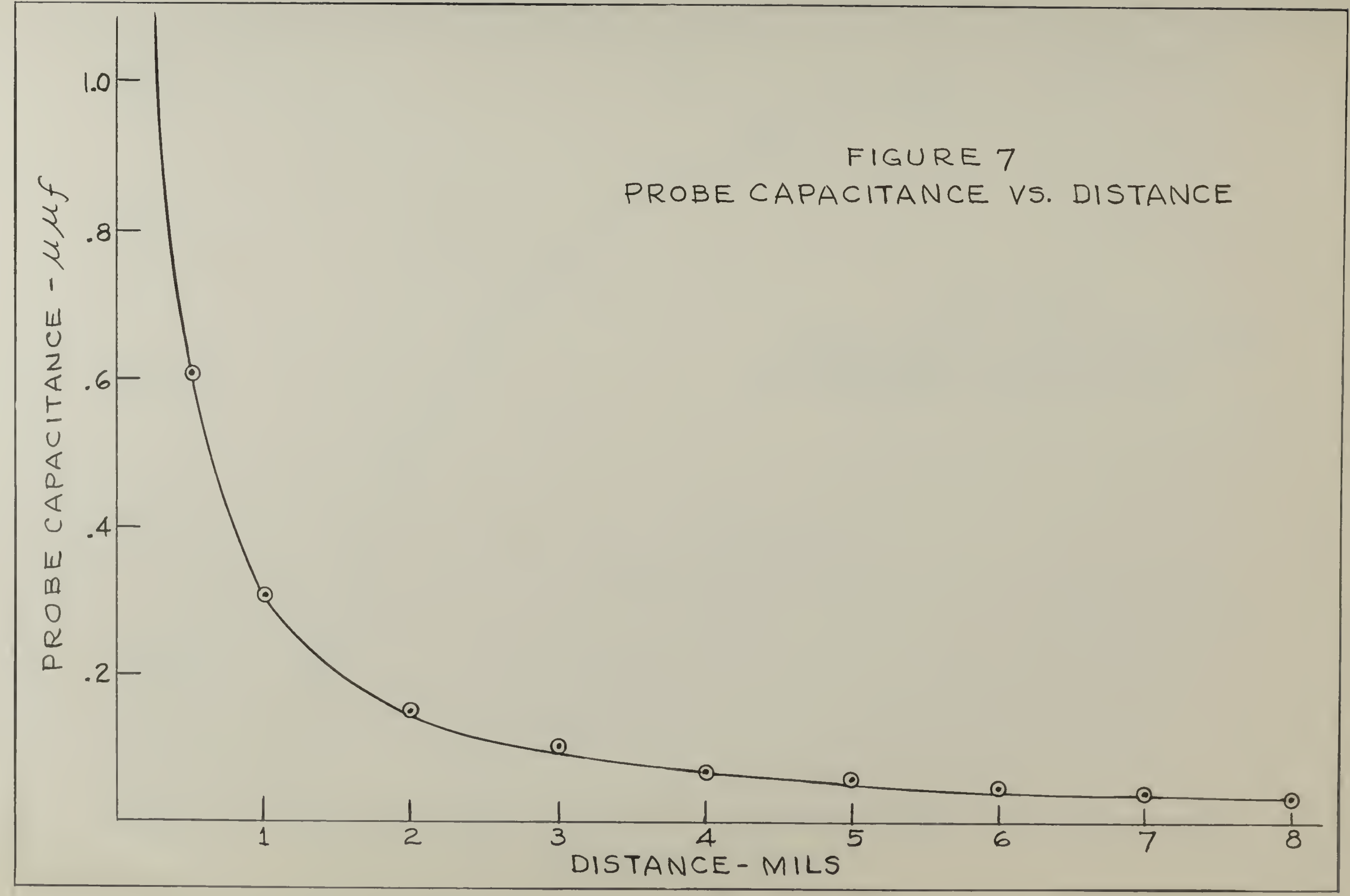
FIGURE 7
PROBE CAPACITANCE VS. DISTANCE

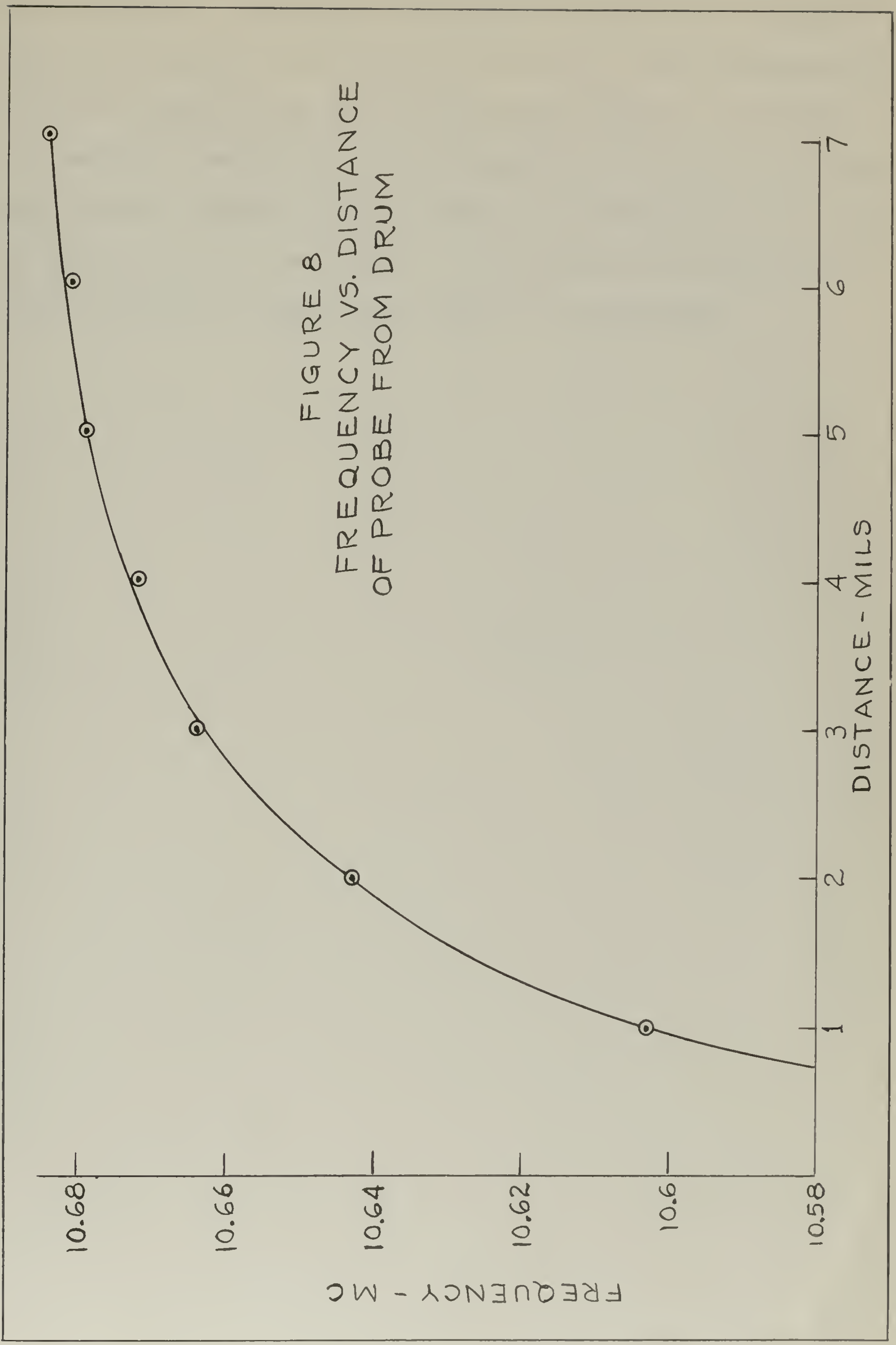

FIGURE 8
FREQUENCY VS. DISTANCE
OF PROBE FROM DRUM

curve (Figure 4). From Figure 8 the sensitivity of a 40 mil diameter probe at a distance of two mils is 25 kc per mil. The discriminator sensitivity is 0.063 mv. per cycle deviation (see Figure 15). Therefore, the theoretical sensitivity of the instrument is 0.667 micro inches per millivolt for a probe 40 mils in diameter at a spacing of 2 mils. Using an oscilloscope with a calibration of 25 millivolts per centimeter, it would be possible to measure variations of 1.5 microinches.

IV. CIRCUITRY

1. The Oscillator

(a) The Oscillator Circuit

Figure 9 is the schematic of the oscillator circuit used. A Western Electric 404A ruggedized pentode with high transconductance, 12,500 umhos, is used. The direct interelectrode capacitances are low: Grid to plate, .04 uuf.; Input, 7.1 uuf. and output 2.9 uuf.

The feedback condensers are a 150 uuf. fixed ceramic, a 6-50 uuf. ganged condenser for coarse balancing and 3-15 uuf. ganged condenser for fine balancing. These values were determined experimentally as the highest which can be used and still have strong oscillations. The feedback circuit is connected to the coil with five feet of RG-63U cable, 10 uuf. per foot, to isolate the chassis from vibration and temperature when the instrument is in use.

(b) The Coil

Figure 10 is a full size drawing of the coil, shield and probe, and Figure 11 a photograph. The coil form is 1" diameter bakelite with close wound wire with 34 turns, #17 heavy formax wire. The turns are covered with Q-max cement to hold them rigidly in place. The coil is mounted vertically in the shield and cemented in place with proxy resin cement. A 3-12 uuf. trimmer capacitor is inserted between the low side of the coil and ground to reduce the effects of the self capacitance of the coil, and for balancing purposes.

The coil data is:

L = 17 uh.

Self Capacitance = 3.5 uuf.

R = 17.2 ohms. at 10.7 mc.

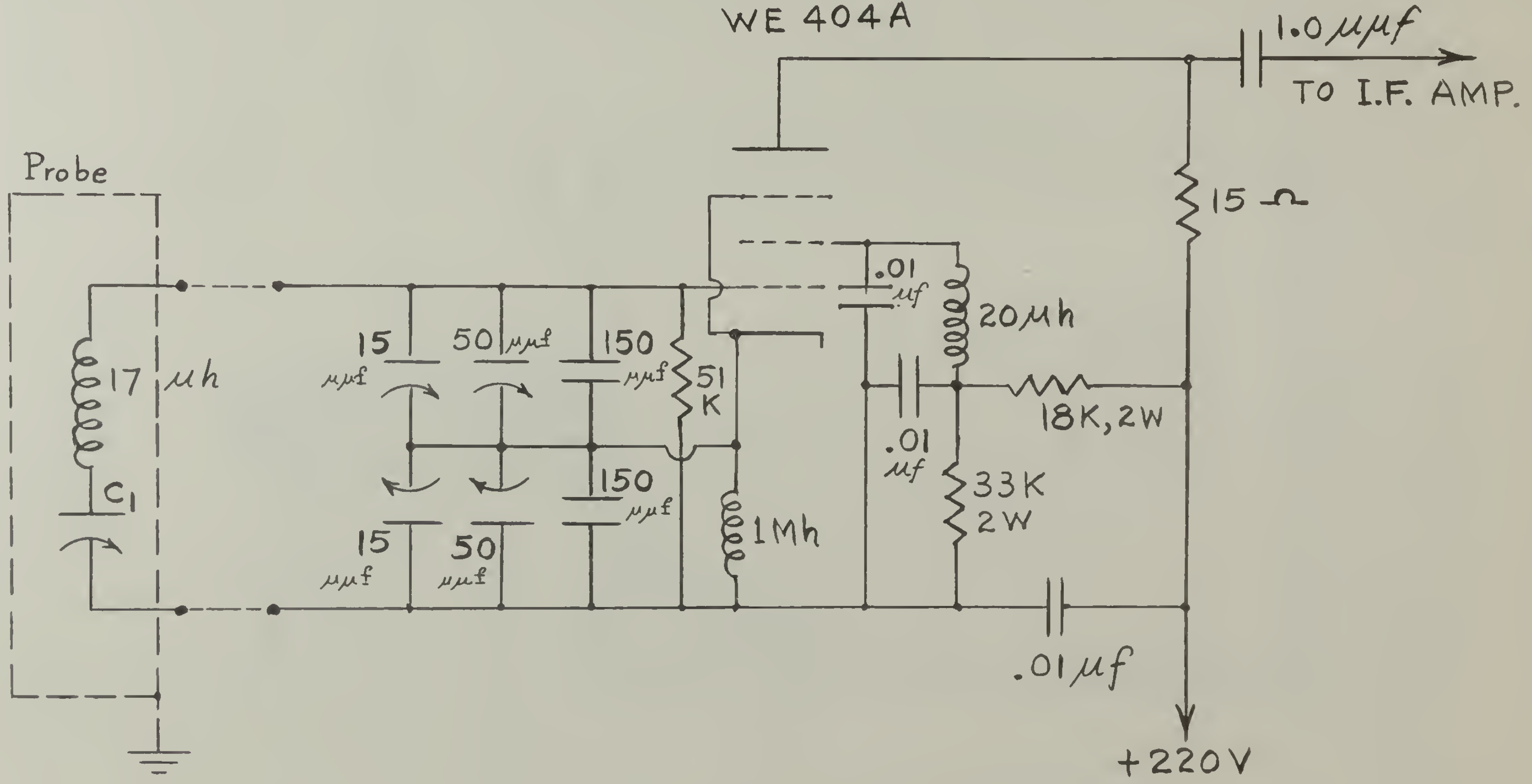

FIGURE 9

OSCILLATOR CIRCUIT SCHEMATIC

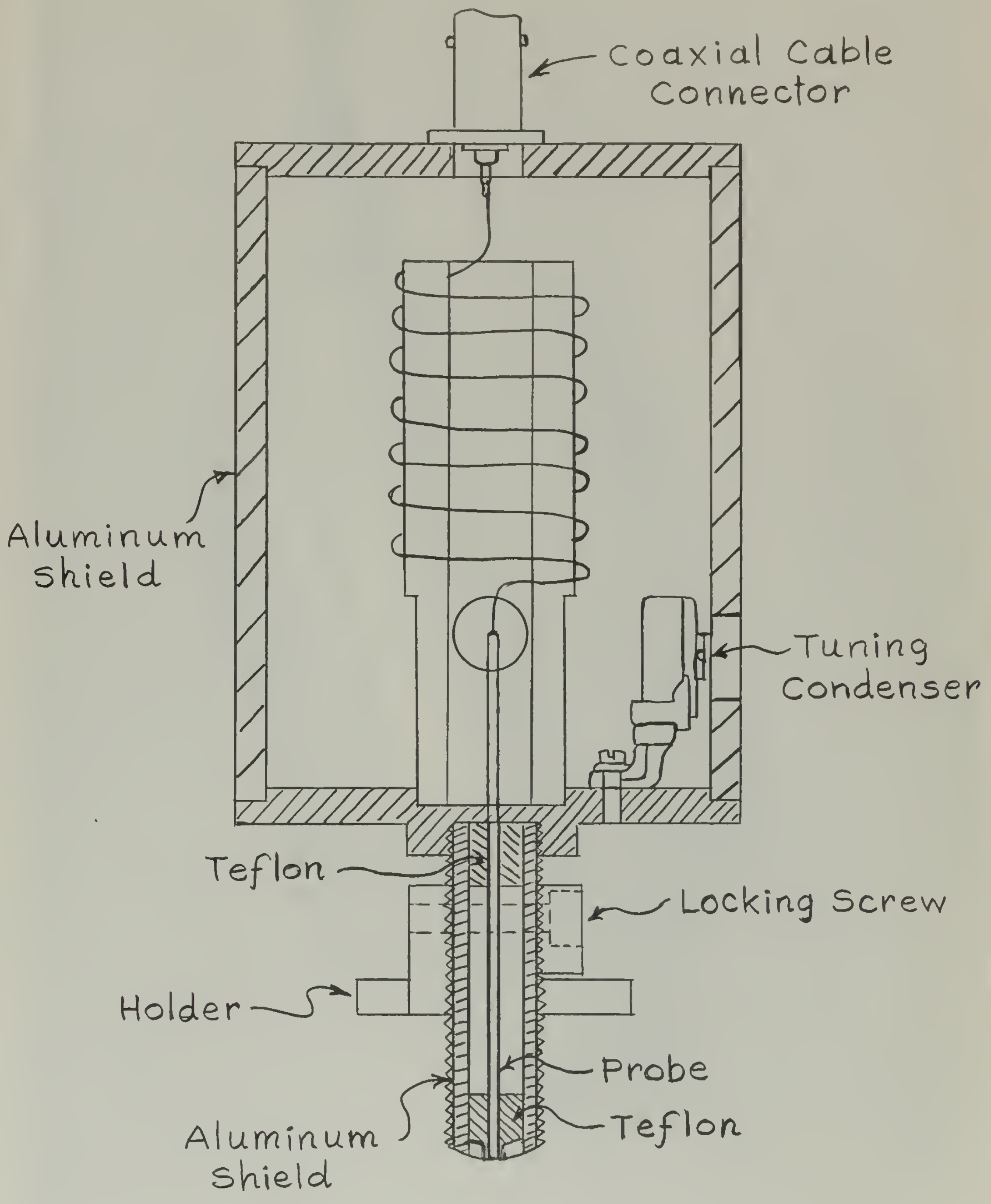

FIGURE 10

PROBE, COIL AND SHIELD (Full Size)

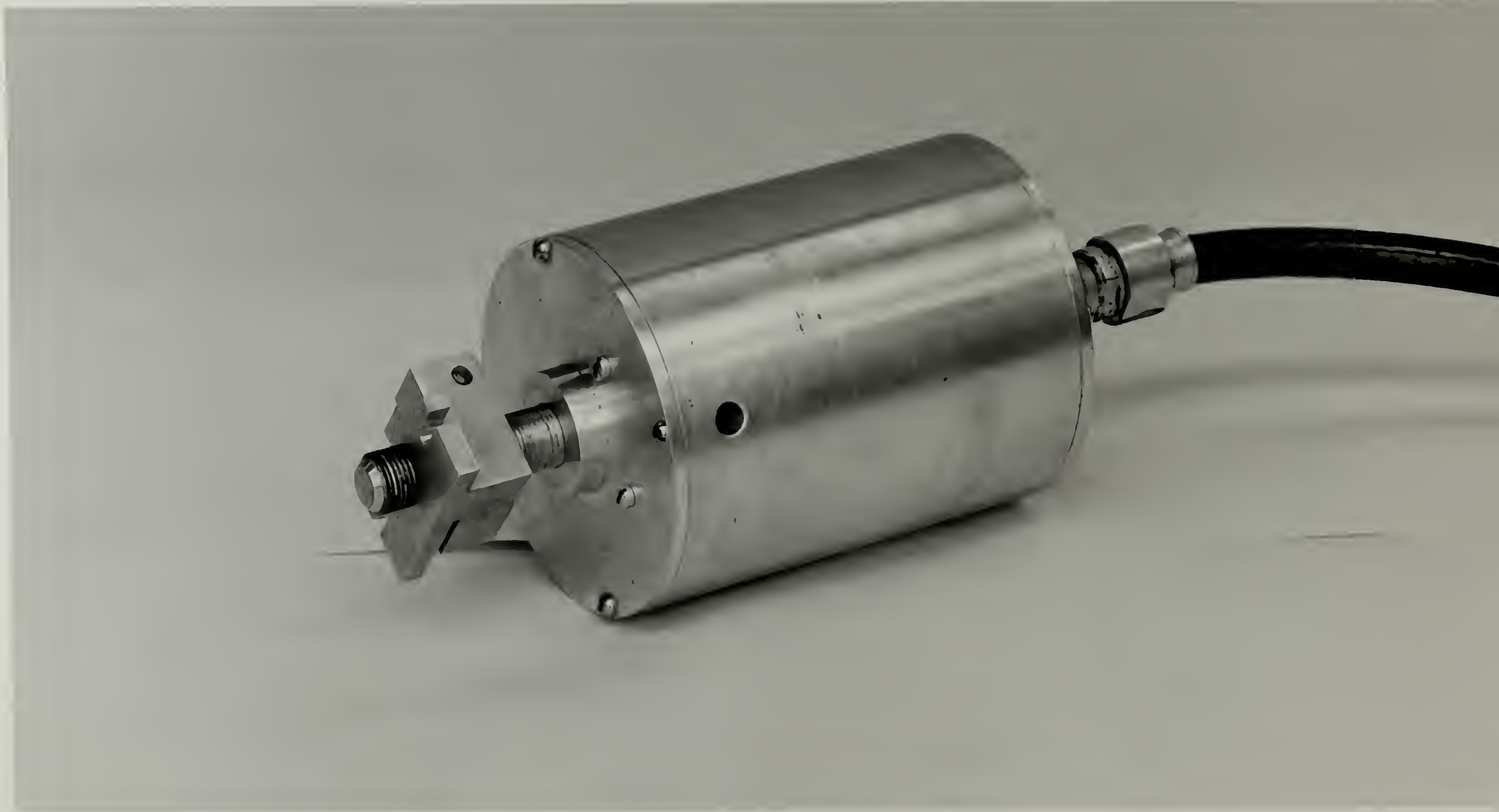

Figure 11. Probe
and Shield

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The effects of the coil shield on the coil constants are an added series resistance of .283 ohms and a reduction of inductance of 2 percent. The attachment of the probe to the coil adds 1.73 ohms r.f. resistance at 10.7 mc.

(c) The Probe

The probe consists of a 3-1/8 inch long silver rod, 40 mils in diameter insulated from the shield with teflon. Although the final shield is to be made of ceramic and plated with copper, the prototype was made of aluminum, due to the shortage of time. The clearance between the shield and the probe was 1 mil due to machining difficulties.

The shield of the probe is threaded with a pitch of 24 turns per inch for insertion into the holder. The coil shield base also threads onto the probe shield.

The probe mount fits the head holder rack of a 4-inch magnetic drum. The probe is locked in the mount with a locking nut to hold the probe rigidly at the desired distance from the drum. A disadvantage of this present design is the large size. The probe cannot be used on an enclosed drum.

(d) Stability

It was expected that the thermal stability of the prototype coil would not be high due to the method of construction; therefore, no temperature tests of the probe and coil were conducted.

Temperature stability of the cable was tested from -50°C. to $+93^{\circ}$C. by means of dry ice and an oven. Figure 12 is a graph of cable capacitance versus temperature. For the total range the change in capacitance is only .075 uuf. per foot, and at room temperatures can be considered negligible.

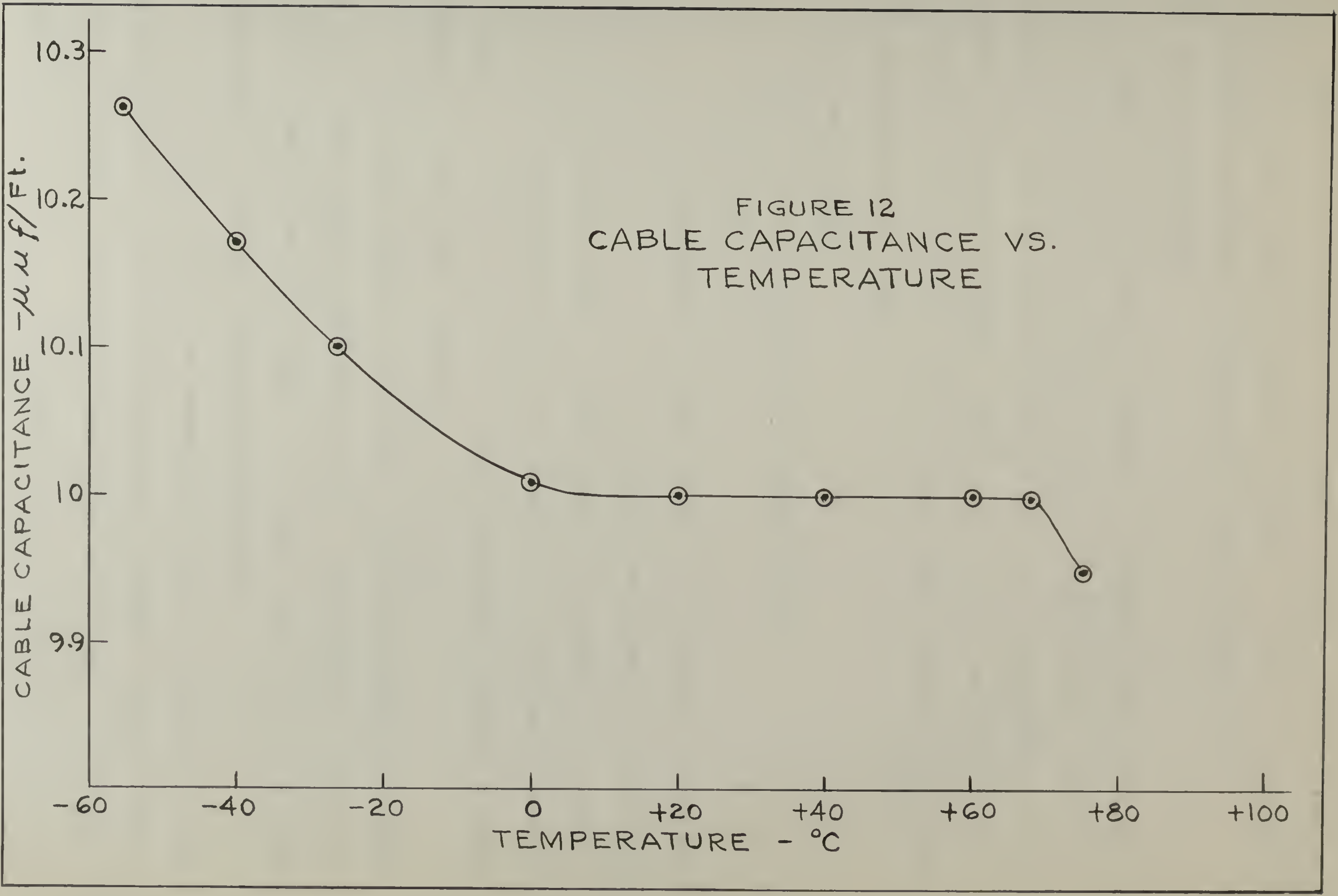


FIGURE 12
CABLE CAPACITANCE VS.
TEMPERATURE

Figure 13 is the graph of the change in frequency versus screen voltage for changes in plate voltage of +10 volts. It will be noted that the maximum stability is obtained with a screen voltage of 110.

2. The I.F. Amplifier

Figure 14 is the circuit schematic of the Collins IF-6 Amplifier purchased from Collins Audio Products Company, Westfield, N. J. The FM I.F. frequency is 10.7 mc. and the sensitivity is 6 to 10 microvolts. The amplifier contains two limiters. Figure 15 is the I.F. amplifier and discriminator characteristic. The linear band width is 280 kc. and sensitivity is 0.063 mv. per cycle.

3. The Meter Circuit

Figure 16 is the schematic of the meter circuit.

(a) The Dynamic Circuit

The first cathode follower circuit is the dynamic meter circuit for the instrument. It is used for coupling the cathode ray oscilloscope to the discriminator output for highly sensitive readings. The ground side of the discriminator output if connected to an adjustable negative voltage for adjusting the output of the first cathode follower to ground potential for use with a cathode ray oscilloscope.

The voltage linearity of the dynamic circuit was measured by using a 1 kc. signal input and measuring the gain. The circuit is linear up to 55 volts peak-to-peak input signal. As maximum output of the discriminator is +12 to -12 volts, the range is satisfactory.

The frequency response was measured by using a 10 volt input signal and measuring the gain as the frequency was increased. The gain began to fall off at 300 kc. and the half power point was 1.08 mc. As the response required was 0 to 50 kc., the frequency response of the meter circuit is

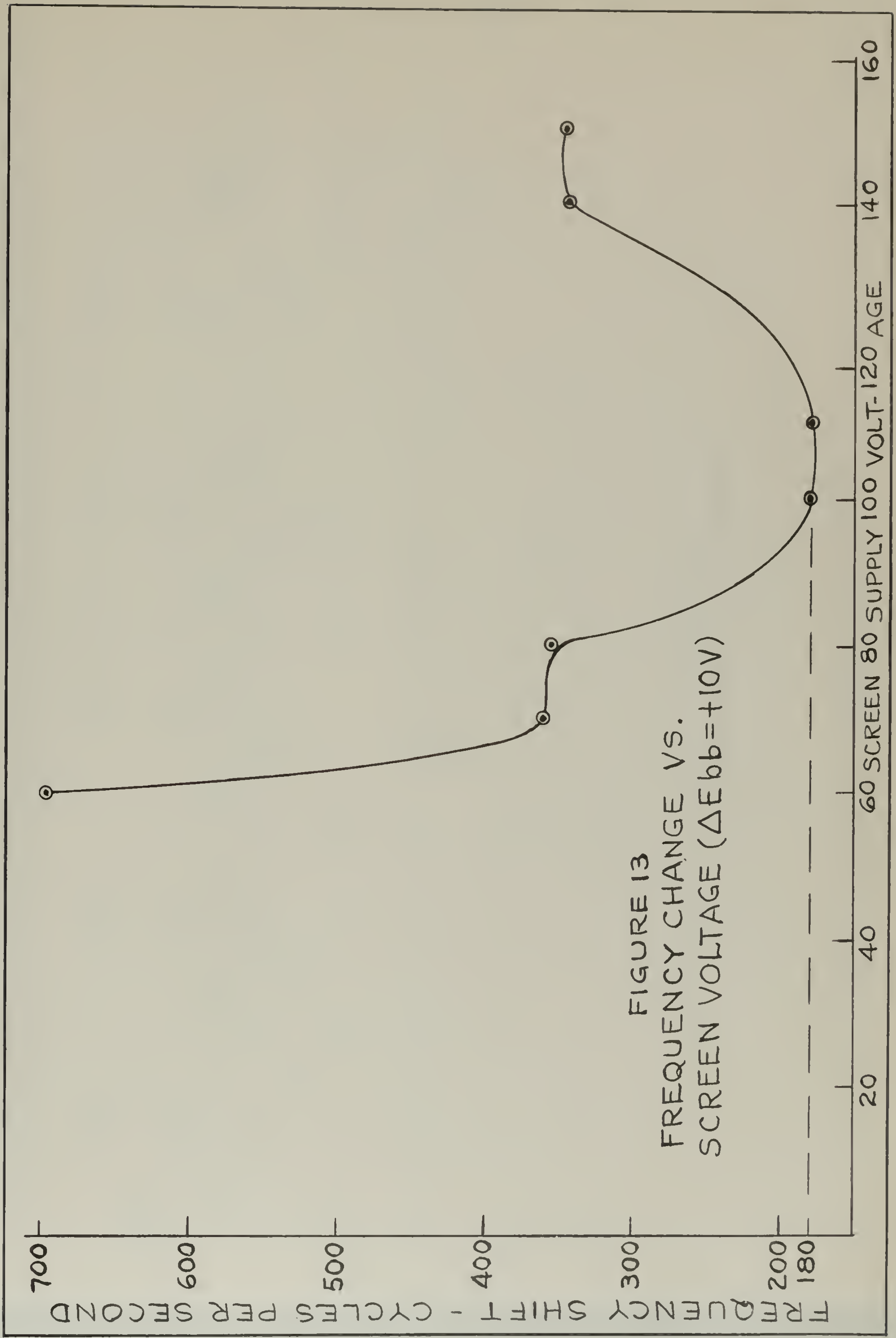


FIGURE 13
FREQUENCY CHANGE VS.
SCREEN VOLTAGE ($\Delta E_{bb}=+10V$)

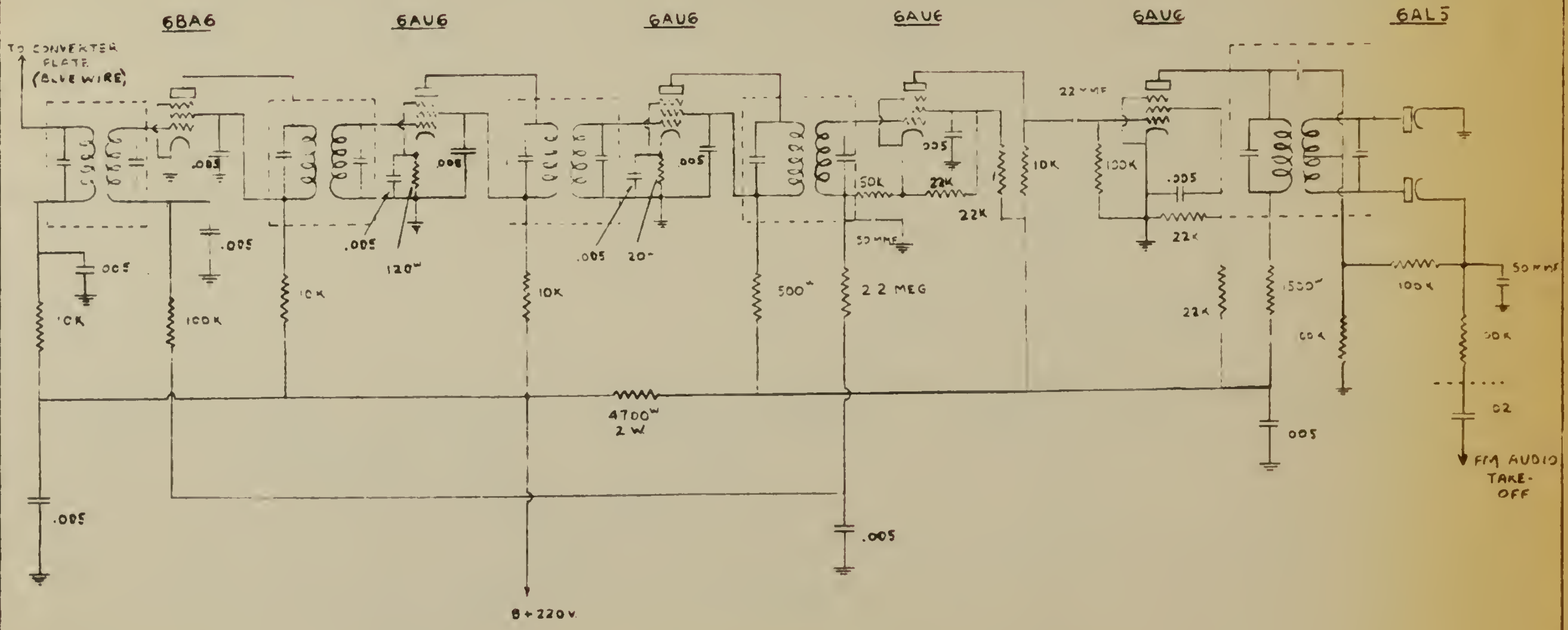
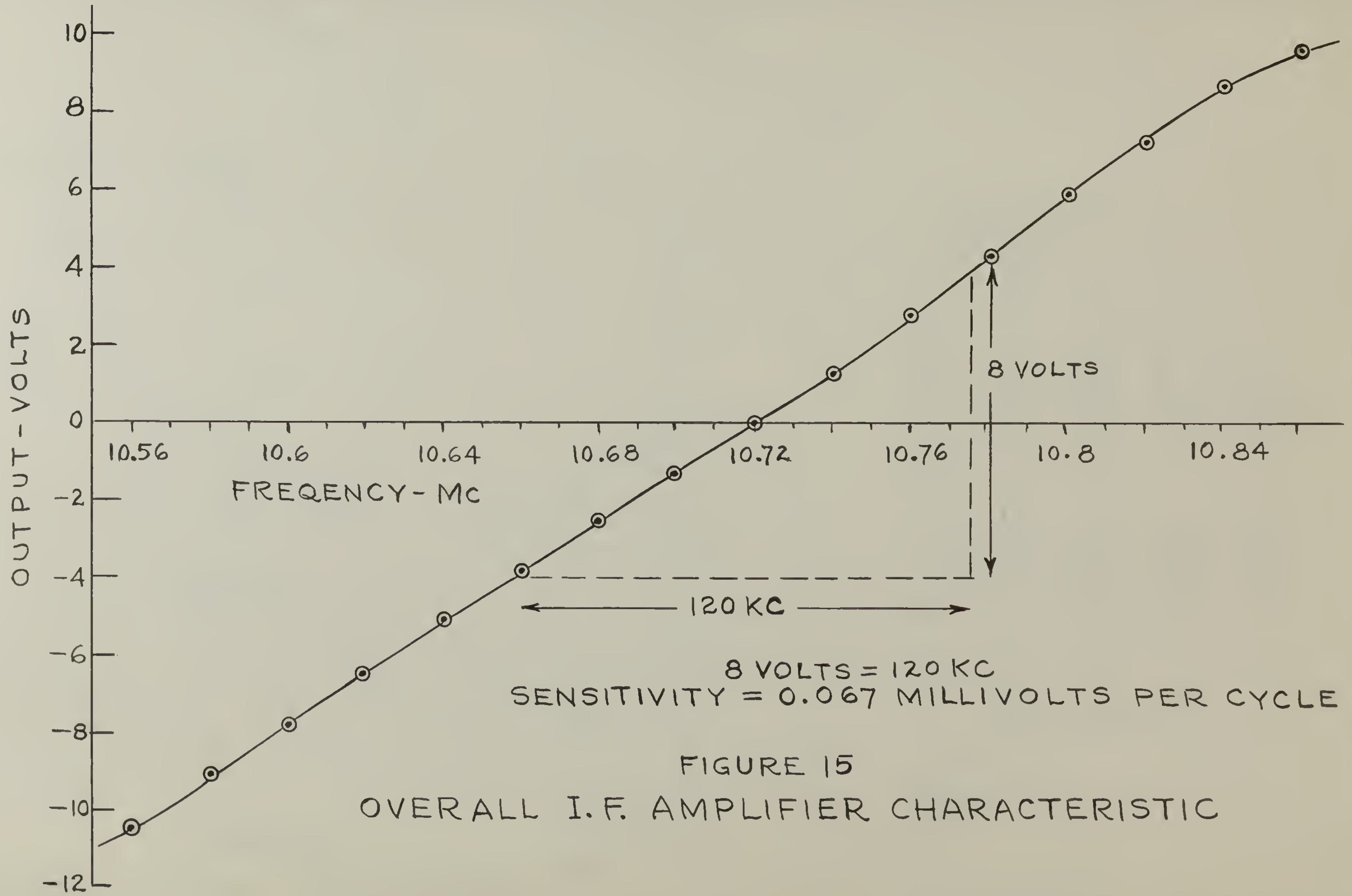


FIGURE 14

I.F. AMPLIFIER SCHEMATIC



8 VOLTS = 120 KC
SENSITIVITY = 0.067 MILLIVOLTS PER CYCLE

FIGURE 15
OVERALL I.F. AMPLIFIER CHARACTERISTIC

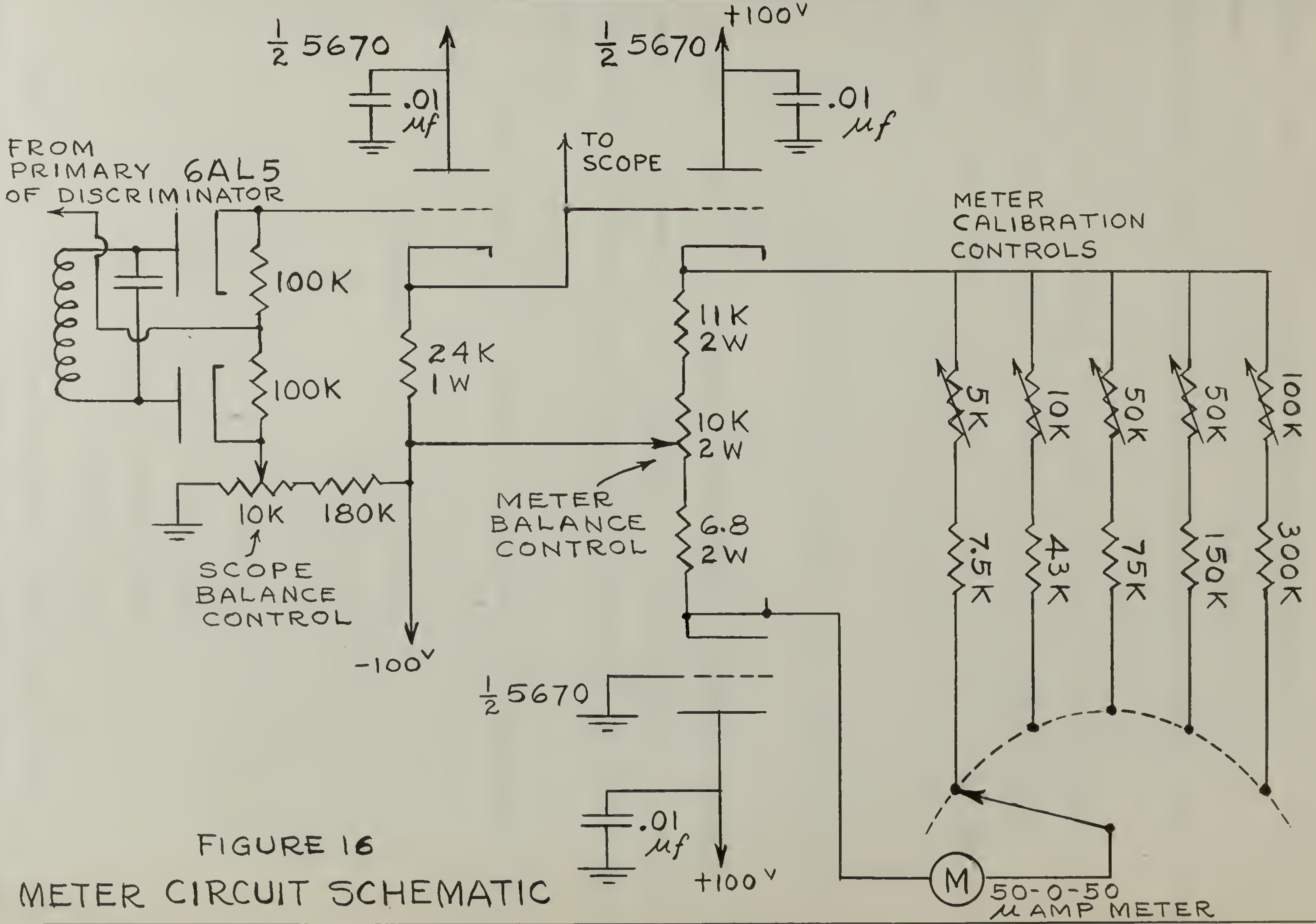


FIGURE 16

METER CIRCUIT SCHEMATIC

satisfactory.

The push-pull cathode follower circuit is the static circuit. A Weston, Model 301, 50 microampere center zero reading meter is used to measure the output. A potentiometer in the cathode circuits of the cathode followers allows adjustment of the meter to zero with no signal from the I.F. amplifier.

The linearity was measured by using a battery and voltage divider. The meter multiplier resistances were set for full scale deflection. All scales are linear except for the most sensitive. Except for the most exacting work, the error of this scale is negligible.

4. Layout

Figure 17 is a photograph of the instrument panel showing location of the various controls.

On the left are the fine and course balancing controls. When the frequency is at the center of the discriminator characteristic and the probe at an infinite distance from ground, these controls are in the horizontal position.

The center control is a six-position switch for the meter scale selection.

Position	Scale
0	Meter not in circuit
1	0.5 volt scale
2	2.5 volt scale
3	5.0 volt scale
4	10.0 volt scale
5	20.0 volt scale

On the right side of the panel are the cathode ray oscilloscope connection posts, the meter zero balance, and on the far right the oscilloscope

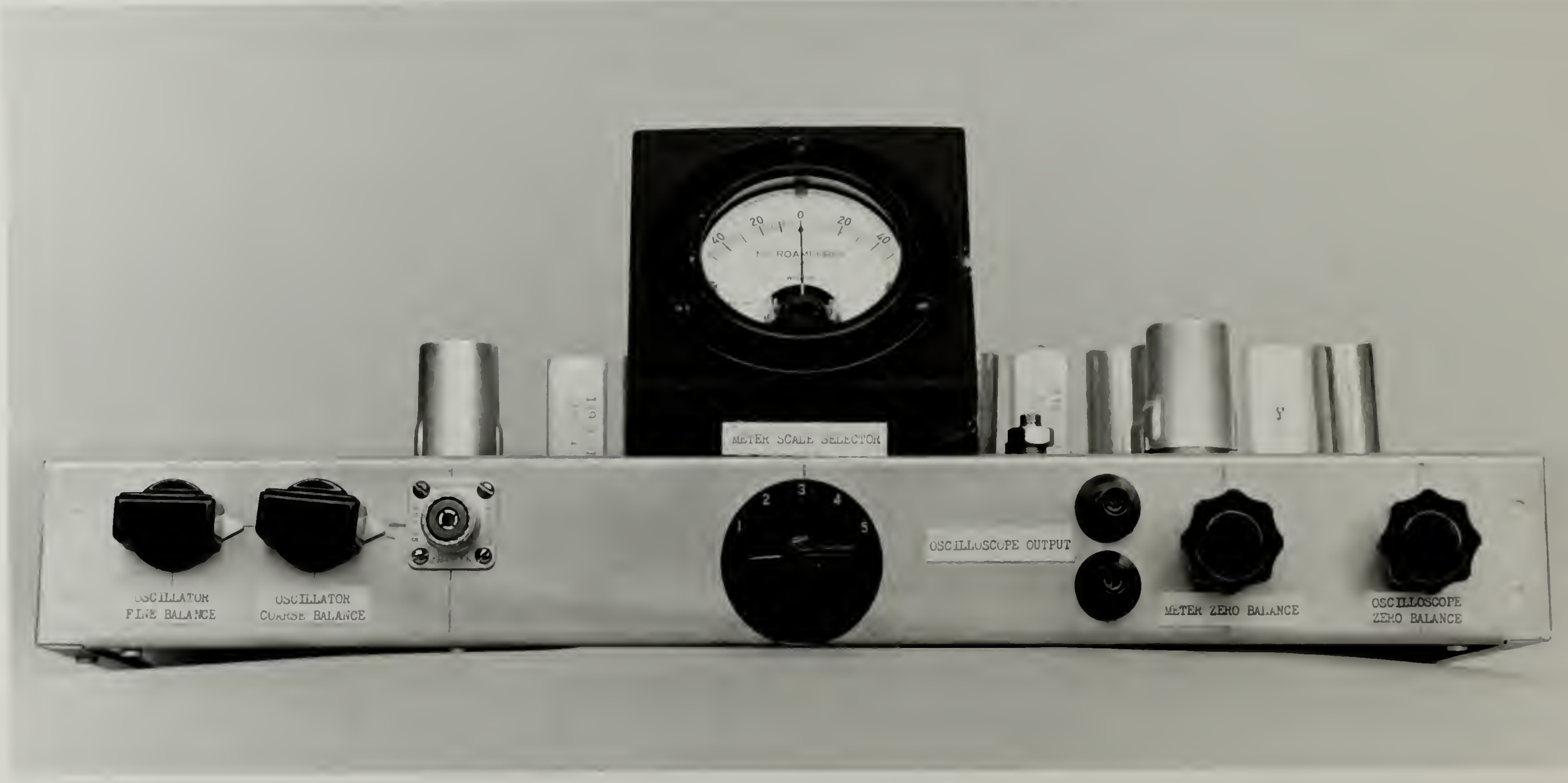


Figure 17.
Instrument Panel

13025

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zero set control.

Figure 18 is a photograph of the complete instrument.

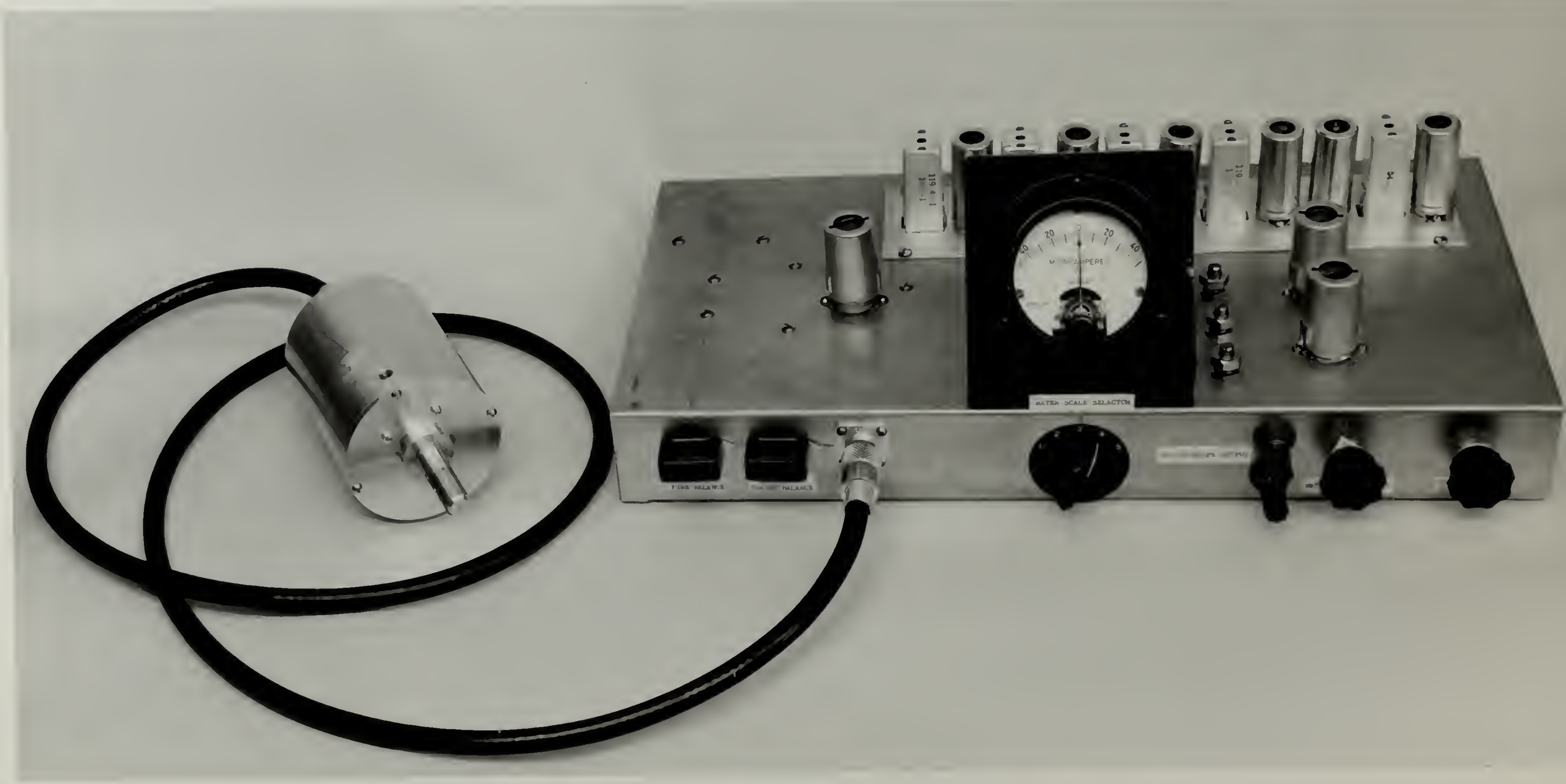

Fig. 18- The Magnetic
Drum Surface Gauge

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MAR

V. CALIBRATION

Since the probe shield is threaded with 24 pitch threads, one three hundred and sixty degree turn of the probe causes a vertical travel of 41.66 mils. A compass rose of two feet diameter was made out of paper covered aluminum. The circle was divided into segments of 1.25°. A 12-inch pointer was attached to the probe shield. Moving the pointer 1.25° caused a vertical travel of the probe of 144.6 microinches. The probe was mounted in its holder on a false "drum" made from a ⊔ shaped piece of aluminum. The probe was rotated and meter readings were taken every 1.25° until the probe short circuited and oscillations stopped. This procedure was done 4 times. The short appeared at the same point in each case. Meter readings varied .1 to .2 volts for each segment of the circle. The readings were then averaged and plotted. Figures 19, 20, 21, and 22 are calibration curves for the different meter scales. Figure 23 is the over-all calibration curve. Note: These calibration curves are for zero position of fine and coarse balance controls. As the gain of the push pull cathode follower is 0.849, these curves must be multiplied by 1/0.849 for oscilloscope presentations.

It will be noted that the above curve is linear from 1.5 mils to 2.5 mils and essentially linear from 3.5 mils to 8 mils. Placing the probe at a distance of 2 mils from the drum, measured variations of ±600 microinches will be linear. In the linear range, at a probe distance of 2 mils, the sensitivity is .84 microinches per millivolt, using the corrected voltage scale. This is in good agreement with the theoretical sensitivity of .67 microinches per millivolt calculated in Chapter II. Using the Tektronix 513D oscilloscope with a calibration of 25 millivolts per centimeter, it is possible to measure variations of 2.0 u inches. Using the meter on

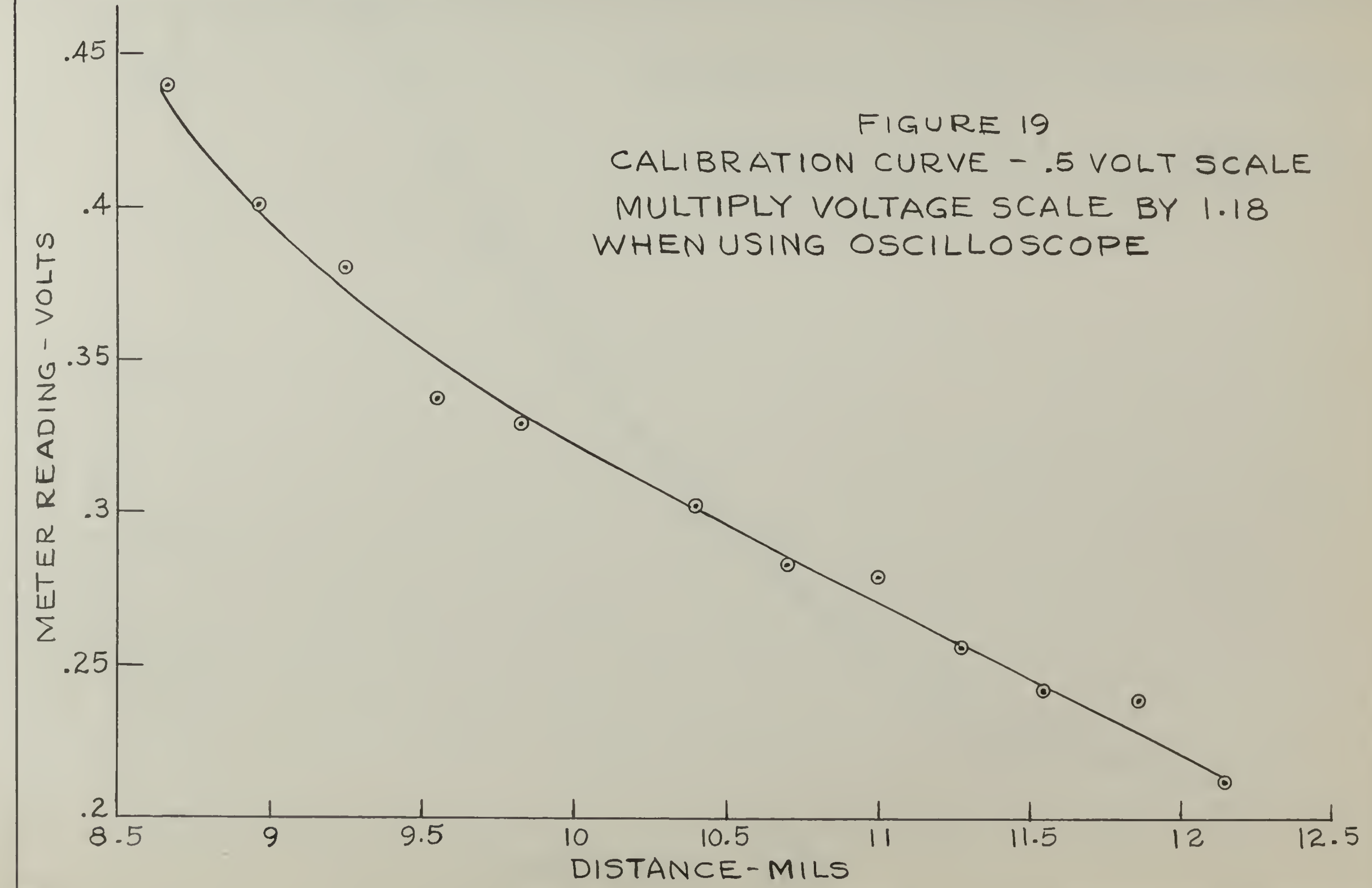


FIGURE 19
CALIBRATION CURVE - .5 VOLT SCALE
MULTIPLY VOLTAGE SCALE BY 1.18
WHEN USING OSCILLOSCOPE

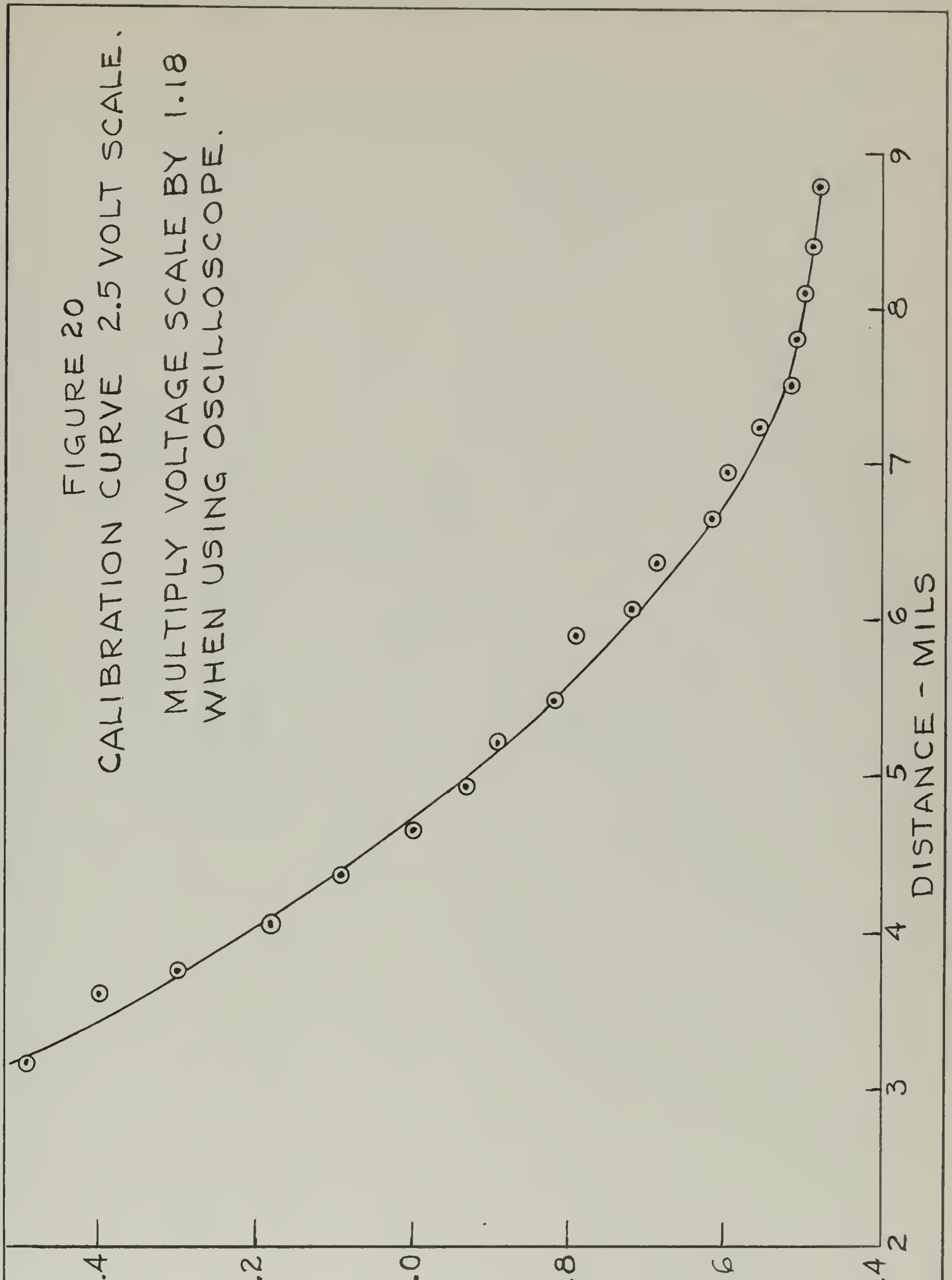


FIGURE 20
CALIBRATION CURVE 2.5 VOLT SCALE.

MULTIPLY VOLTAGE SCALE BY 1.18
WHEN USING OSCILLOSCOPE.

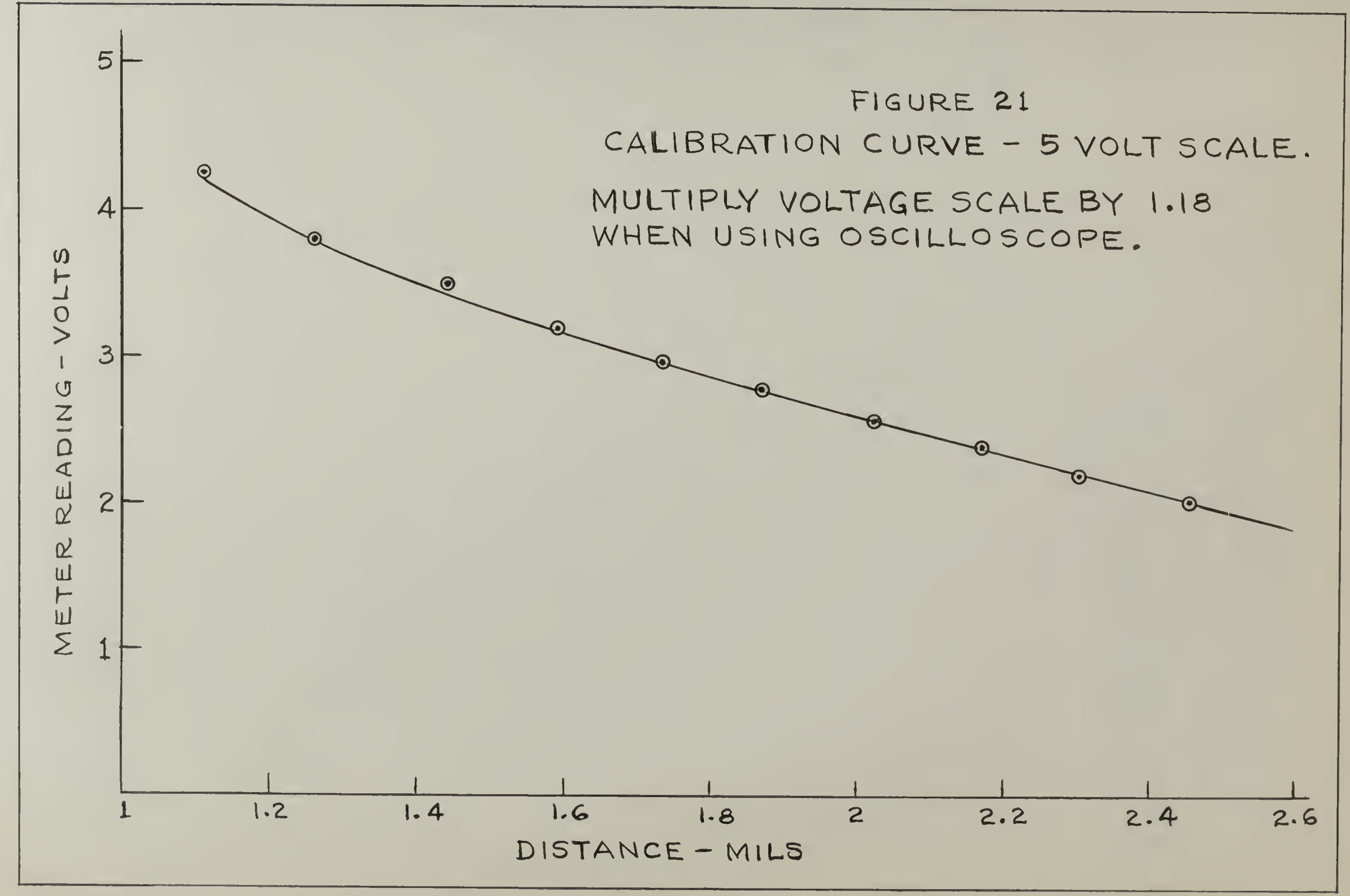


FIGURE 21

CALIBRATION CURVE - 5 VOLT SCALE.

MULTIPLY VOLTAGE SCALE BY 1.18
WHEN USING OSCILLOSCOPE.

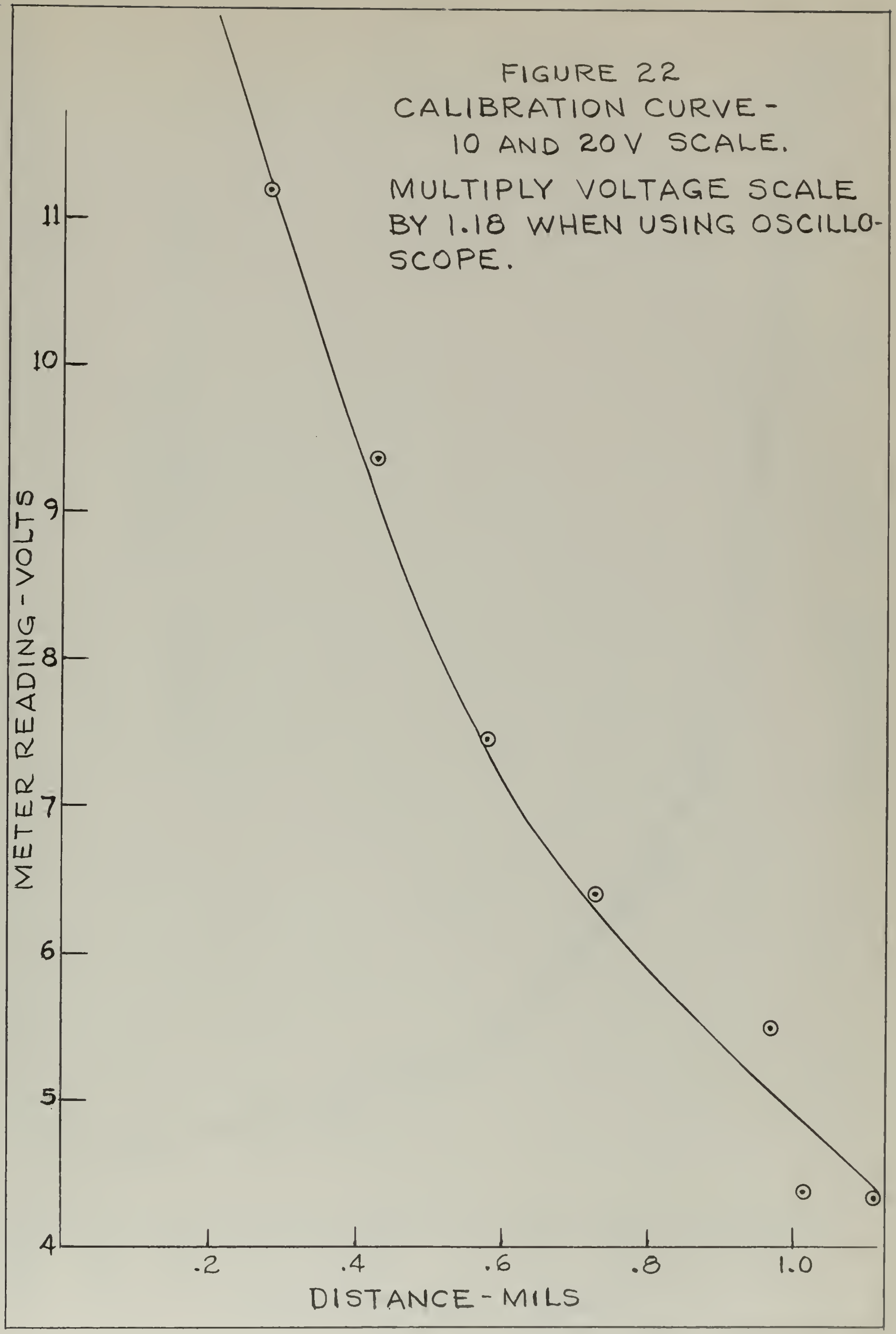


FIGURE 22
CALIBRATION CURVE -
10 AND 20 V SCALE.

MULTIPLY VOLTAGE SCALE BY 1.18 WHEN USING OSCILLOSCOPE.

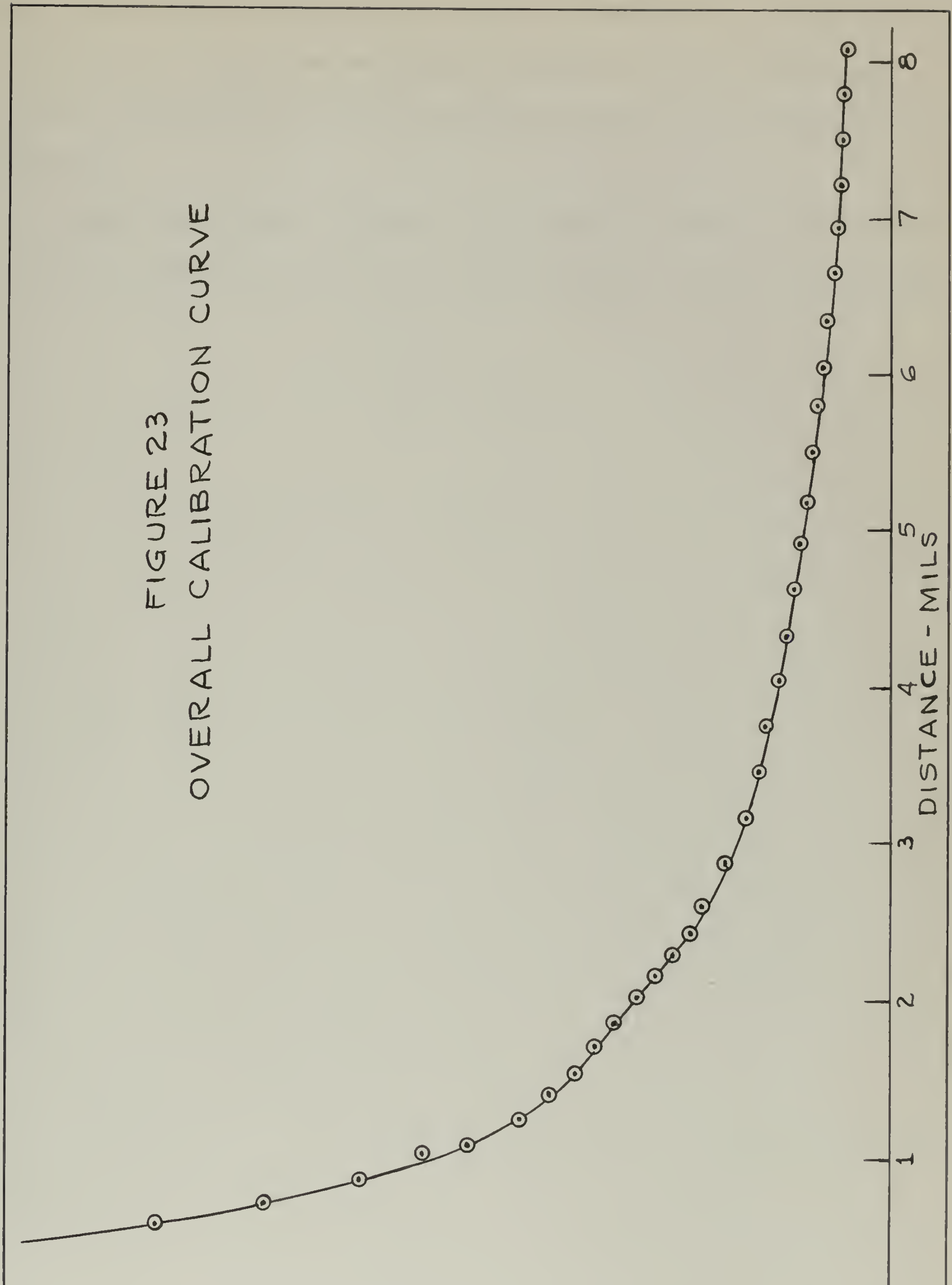


FIGURE 23
OVERALL CALIBRATION CURVE

the .5 volt scale it is possible to read to one-fifth of a division. Variations of 4 u inches can be measured statically in the linear range since the sensitivity of the static meter circuit is .72 microinches per millivolt.

Using a lower probe distance will increase the sensitivity but the error in readings and oscillator instability makes this of little value.

VI. OPERATION

1. Balancing of the Instrument

(a) Use external regulated power supplies to provide the necessary voltages, 220 volts d-c for oscillator and I.F. amplifier and plus and minus 100 volts d-c for the meter circuit.

(b) With no voltage supply to the oscillator and I.F. amplifier, adjust the Oscilloscope Zero to give zero voltage across the oscilloscope connection terminals. Then adjust the Meter Zero so that the meter reads zero output.

(c) Apply plate voltage to the oscillator and I.F. amplifier.

(d) With the Coarse and Fine Balance Controls in zero position (horizontal), tune the oscillator to center frequency by use of a screw driver on the variable condenser within the coil shield. A small hole has been drilled in the shield for this adjustment. The center frequency can be noted by zero discriminator output. For this adjustment the probe must be more than a quarter inch from any grounded metal.

(e) Small adjustments of the oscillator frequency can be made by use of the Coarse and Fine Balance Controls, but there is the chance of moving the oscillator frequency up or down into the curved portion of the discriminator characteristic.

2. Attachment of the Probe to the Drum

(a) Attach the probe holder on the window of the head holder in the drum casing (see Figure 24).

(b) Screw the probe into the holder. The probe travels 41.66 mils per revolution. Shims may be used to set the distance of the probe from the drum. Because slop in the rotor bearings might cause the drum surface to strike the probe on starting of the drum motor, a better method of

setting the probe distance is to start the drum motor with the probe a large distance away, say ten mils. When the drum gets up to speed, turn the probe down until the meter reads the voltage of the desired distance, taken from the calibration curve. During dynamic measurements the meter reads the average distance of the probe from the drum; this measurement is valuable in certain types of testing.

At a distance of 2 mils (3.06 volts on the 5 volt scale), the oscilloscope presentation is linear for variations of 600 u inches on either side of 2 mils. For larger variations or for other probe spacings, take photographs of the oscilloscope presentations and resort to the calibration curves.

It should be noted that the drum rotor should be grounded so that the capacitance between the drum and its casing is not in series with the probe capacitance and thereby introduce errors into the measurements.

3. Applications

This instrument can be used to measure variations on the surface of any conducting material if the probe is held in a stationary position and the surface moved under it.

It can be used for selection of parts by passing parts under it and discarding those showing greater size variation than tolerances allow.

It can also be used for the measurement of dielectric constants. If the thickness of the sample is known, the increase of the instrument meter indication above that of its reading in air is a direct indication of the dielectric constant.

VII. RESEARCH

The surface gauge was first used on a 4-inch drum, 10 inches in length, with windows for 10 writing heads. The probe mounted on this test drum is shown in Figure 24. The motor was 3,600 rpm, 115 volts, 60 cycles, with a step up ratio of 2.23 to give a drum speed of 8,000 rpm. A considerable amount of jitter was noted on the oscilloscope presentation. At first it was thought that this was an indication of instability of the oscillator due to vibration of the coil. Removal of the coil and probe from the drum and the application of mechanical impulses to it by striking it gave indication of voltage variations less than one-tenth those noted while the probe was on the drum. The probe was replaced and mechanical impulses were applied to the drum and to the writing head rack. Nine-tenths of the jitter was coming from the vibration of the rack which holds the heads. The probe was merely responding to the motion of the beam it was mounted on. This drum had a maximum variation on its surface of 35 micro inches but because of dynamic rotor vibration, etc., the oscilloscope could not be synchronized for photographs.

The surface gauge was next used on a 4-inch cobalt-nickel finished test drum with large eccentricity. Figure 25 is a photograph of the probe mounted on this drum. The probe was placed at a distance of 2 mils from the drum. The oscilloscope calibration was 0.5 volts per centimeter. This is 420 u inches per centimeter on the oscilloscope screen. Figure 26 is a photograph of the oscilloscope presentation and an extended plot of the curve. The sinusoidal variation is due to drum eccentricity as the variation of the distance of the surface of a cylinder from its geometric center when rotated about a point other than its geometric center is a sinusoidal function (see Appendix III). Examination of the drum on

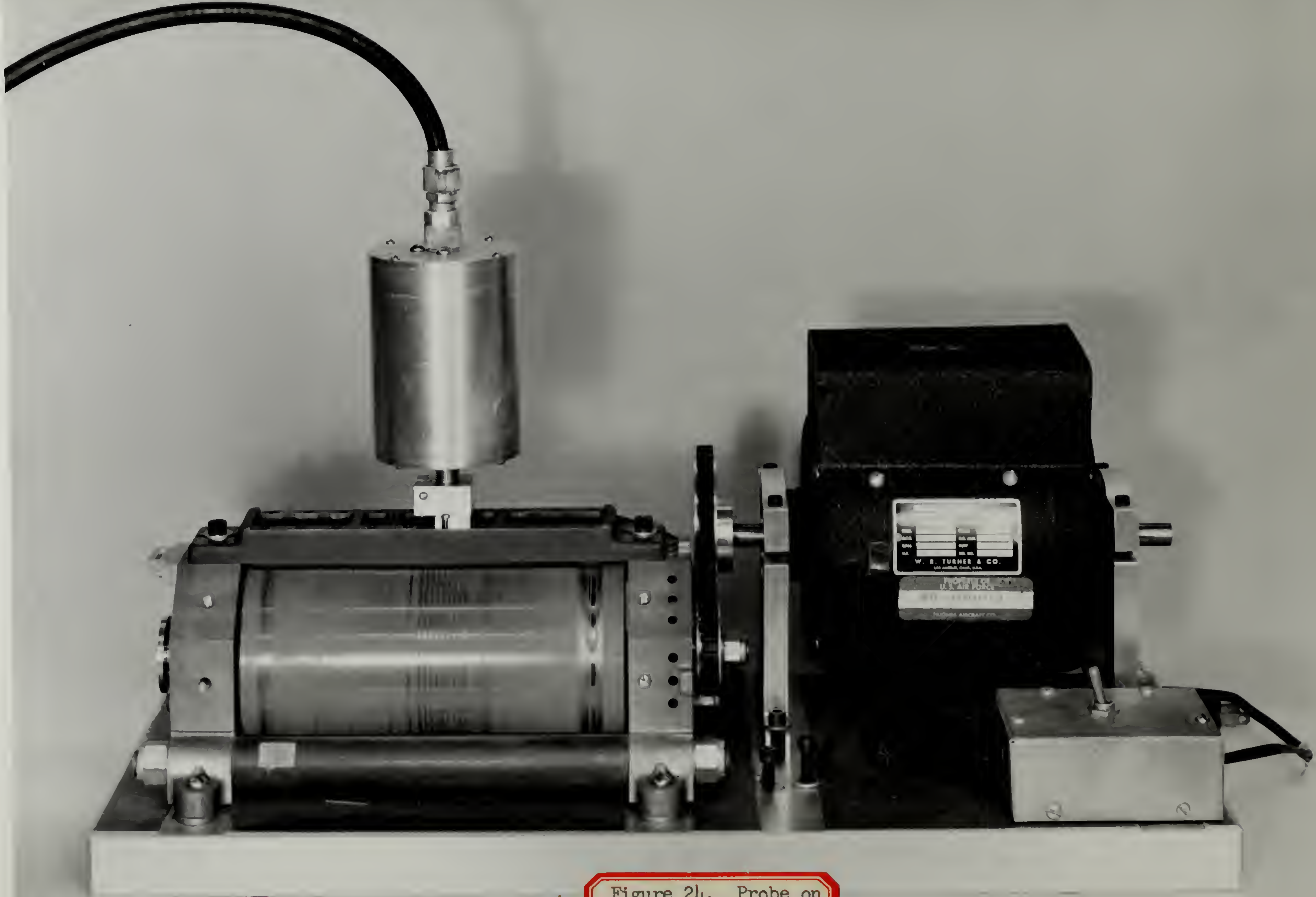


Figure 24. Probe on
Oxide Coated Drum

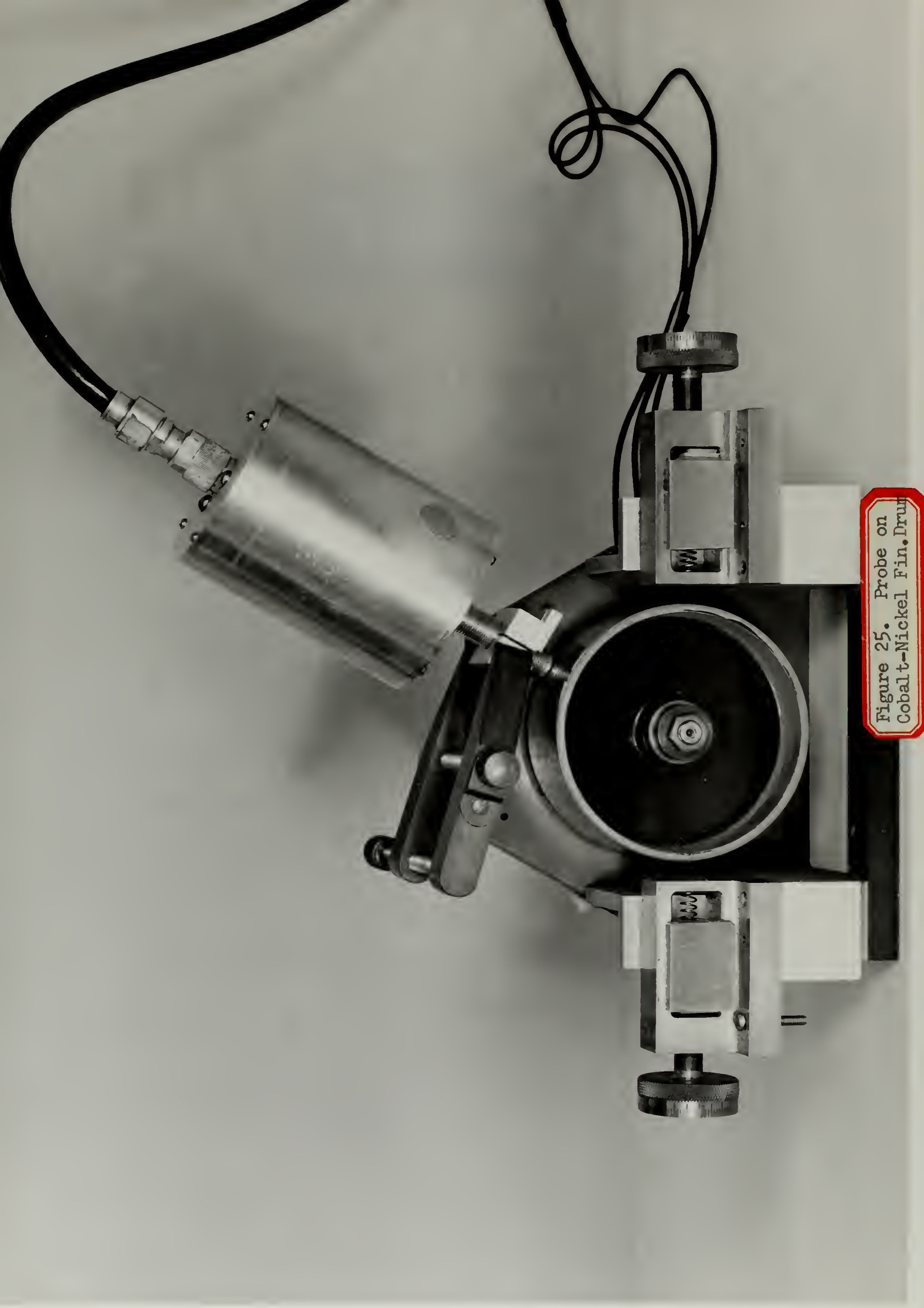


Figure 25. Probe on Cobalt-Nickel Fin. Drum

MA

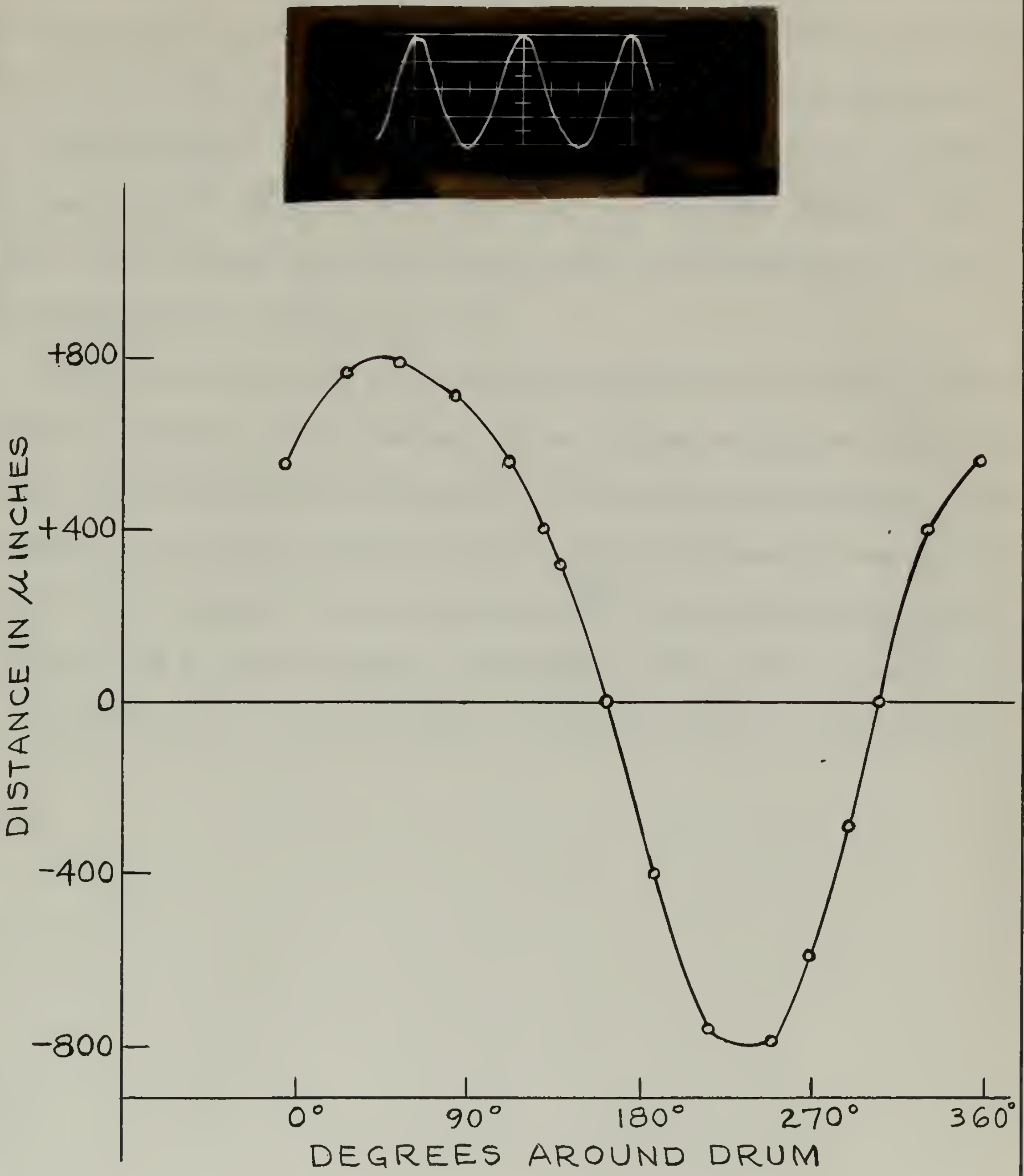


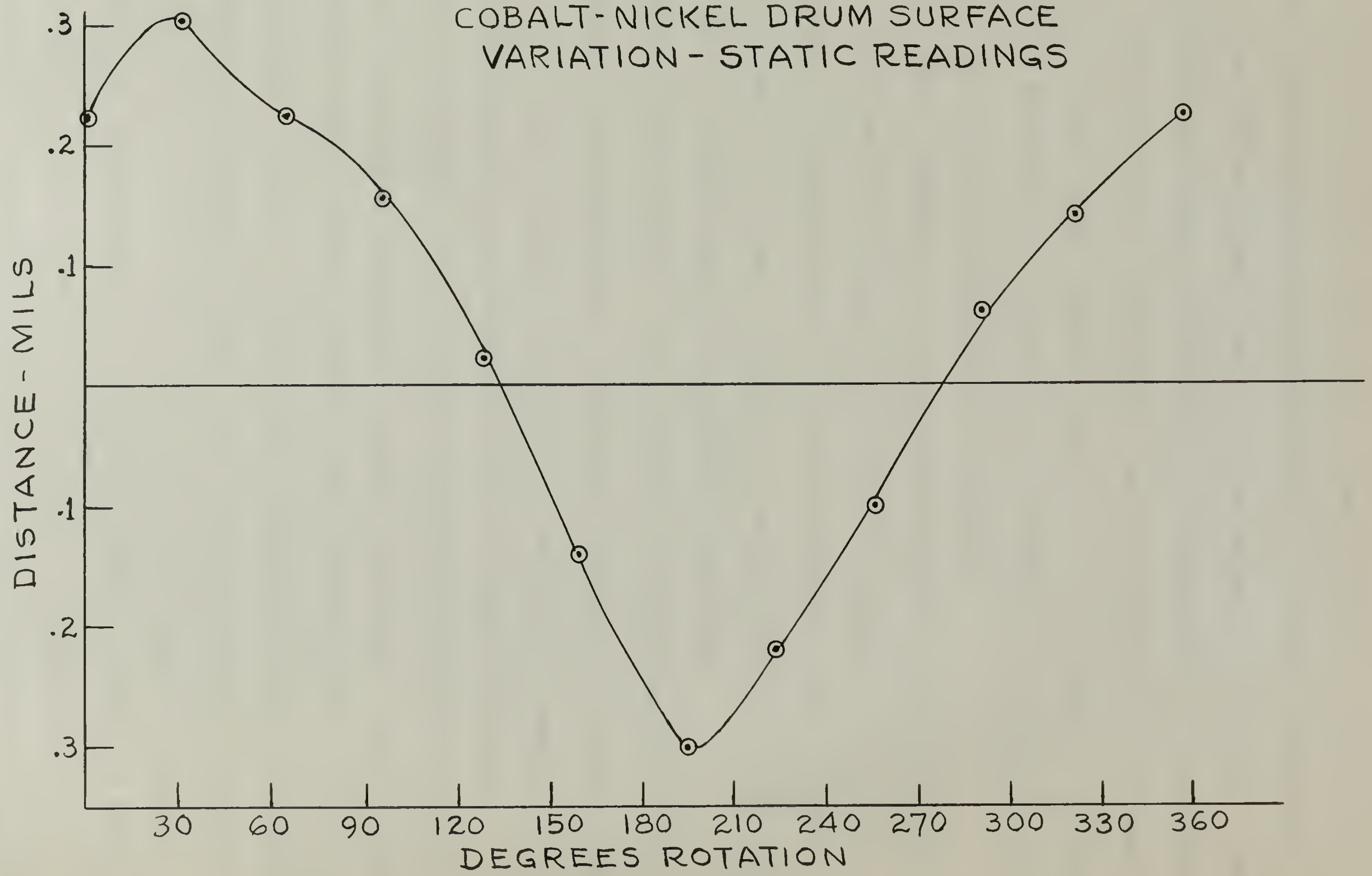
FIGURE 26
PHOTOGRAPH OF OSCILLOSCOPE
PRESENTATION AND PLOT

an expanded sweep showed small variations on the surface of 12 microinches in height with a 28 mil period. As the resolution of the probe decreases for variations on the surface with less than a 200 mil period, the amplitude of this small variation is probably 4 times as large as measured.

Figure 27 is a plot of the surface variation under static conditions. The amplitude of variation is 37.5 percent of that under dynamic conditions. 62.5 percent of the amplitude during dynamic testing is due to centrifugal force, bearing slop, etc.

Since the frequencies due to "out-of-round" and eccentricity defects differ by a factor of two, the amplitudes of these variations can be measured with a wave analyzer connected to the oscilloscope terminals. Measurements of the cobalt-nickel finished test drum showed the amplitude of eccentricity, measured at 133 cycles, is ~~0.42~~ 3.01 volts, and the amplitude variation due to out-of-roundness, measured at 266 cycles, is ~~2.58~~ 0.42 volts. The variation due to "out-of-round" is 14% of that due to eccentricity.

FIGURE 27
COBALT-NICKEL DRUM SURFACE
VARIATION - STATIC READINGS



VIII. CONCLUSIONS AND RECOMMENDATIONS

It should be noted that this was a ten-week project and short cuts had to be taken that would not normally occur in research. The present Magnetic Drum Surface Gauge is not a polished industrial instrument. Even so, the present instrument is very useful for measurements at room temperature. Its sensitivity is much greater than the original specifications. Its resolution and thermal stability are not as high as might be desirable, but with the modifications indicated below the Magnetic Drum Surface Gauge will be a valuable precision industrial instrument.

The present instrument is extremely useful for the accurate measurement of variations of 2 microinches or more. This exceeds the initial specification of a sensitivity of 25 to 50 microinches. The instrument is linear from 1.5 to 2.5 mil distance from the rotor surface so the meter can be made to be read directly in distance in this region.

The short term stability of the oscillator is approximately $\pm 12.2 \times 10^{-4}$ percent at room temperature. Therefore, the error is 5.5 microinches or less for a single reading. If a number of readings are taken over a 5 to 10-minute period and averaged, this error is greatly decreased.

The coil form and shield may be constructed from ceramic material to increase the mechanical and thermal stability. Lavite can be easily machined and then fired to form a rigid coil form and housing with a low thermal coefficient. The coil form can then be flashed with silver and plated with copper to the thickness desired. The coil form can then be grooved on a lathe with the pitch desired. The lavite shield would be flashed with silver and copper plated on the external surface. This would allow a great reduction in the size of the coil shield. Designing the probe with enough self capacitance to tune the coil to 10.7 mc. would reduce the

size of the shield by eliminating the tuning condenser in series with the coil.

Use of an iron core coil will reduce the size of the coil but will cause greater thermal instability.

The use of an oscillator at a higher frequency with a beat frequency oscillator or a higher frequency I.F. amplifier will increase the sensitivity, but presents greater stability problems. Use of a narrower band discriminator, along with a B.F.O. at a low frequency, will give greater sensitivity, but at the expense of a smaller frequency shift range.

The decision to make a cylindrical probe 40 mils in diameter was governed by the shortage of time and machining difficulties. Making the probe of larger wire will give the instrument greater dynamic range. Making it of smaller wire will increase the resolution. Using a razor blade or knife edge will decrease the problem of area resolution. Several different shaped probes would greatly extend the usefulness of the instrument.

APPENDIX I

Derivation of relationship between frequency and probe distance.

Let d be the distance of the probe from the drum. Assuming that the capacitance variation is that of a parallel plate condenser where:

$$c = \frac{k_1}{d} \qquad (1)$$

Now the frequency varies inversely as the square root of the capacitance. Therefore,

$$f = \frac{k_2}{\sqrt{c}} \qquad \text{Or:} \qquad c = \frac{k_2^{\,2}}{f^2} \qquad (2)$$

Letting $k_2^{\,2} = k_3$ and equating equations (1) and (2):

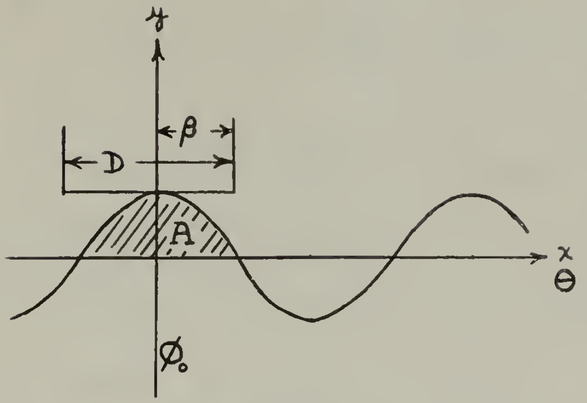
$$\frac{k_3}{f^2} = \frac{k_1}{d}$$

or:

$$k_1 f^2 = k_3 d$$

APPENDIX II

Derivation of the resolution correction factor for recurring defects with very short periods.



Let D be the diameter of the probe, x = the horizontal distance on the drum surface, ϕ_o any position of the probe center on the drum surface, and λ = the wave length of the sinusoidal surface.

$$A = \frac{1}{D}\int_{\phi_o - \beta}^{\phi_o + \beta} K \cos \theta \, dx$$

Now $\theta = \frac{2\pi x}{\lambda}$, therefore $\frac{dx}{d\theta} = \frac{\lambda}{2\pi}$ and $\beta = \frac{\pi D}{\lambda}$

Therefore,

$$A = \frac{K}{D}\int_{\phi_o - \frac{\pi D}{\lambda}}^{\phi_o + \frac{\pi D}{\lambda}} \frac{\lambda}{2\pi} \cos \theta d\theta = \frac{K \lambda}{2\pi D}\Big[\sin \theta\Big]_{\phi_o - \frac{D\pi}{\lambda}}^{\phi_o + \frac{D\pi}{\lambda}}$$

$$= \frac{K\lambda}{2\pi D}\left[\sin\left(\phi_o + \frac{D\pi}{\lambda}\right) - \sin\left(\phi_o - \frac{D\pi}{\lambda}\right)\right]$$

$$= \frac{K\lambda}{2\pi D}\left[\sin \phi_o \cos \frac{\pi D}{\lambda} + \cos \phi_o \sin \frac{\pi D}{\lambda} - \sin \phi_o \cos \frac{\pi D}{\lambda} + \cos \phi_o \sin \frac{\pi D}{\lambda}\right]$$

$$= \frac{K\lambda}{\pi D}\left[\cos \phi_o \sin \frac{\pi D}{\lambda}\right]$$

To determine the values of ϕ for which the above expression is a maximum and a minimum, differentiate with respect to ϕ, set equal to zero, and solve for the values of ϕ.

$$\frac{dA}{d\phi} = \frac{K\lambda}{\pi D} \sin \frac{\pi D}{\lambda} \sin \phi_o = 0$$

$$\therefore \phi = n\pi$$

Therefore

$$A = \frac{K\lambda}{\pi D} \cos n\pi \sin \frac{\pi D}{\lambda}$$

Or:

$$A = \pm K \frac{\lambda}{\pi D} \sin \frac{\pi D}{\lambda}, \quad \text{since } \cos n\pi \text{ is always } \pm 1.$$

Since $\lim\limits_{x \to 0} \frac{\sin x}{x} = 1$, the amplitude correction is essentially unity for large wave lengths.

Figure 28 is a plot of A for values of D/λ from .001 to 6.

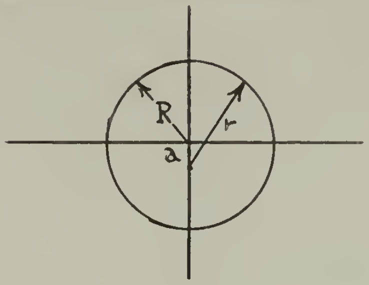
NOTE: This derivation applies to the case where the circumference of the drum is much greater than the probe diameter; i.e., the drum surface is treated as a flat plane with sinusoidal variations superimposed on it.

The effect of fringing was neglected and the axial width of the defect was assumed to be greater than the diameter of the probe. These effects modify the output amplitude in that it does not actually go to zero for D/λ equal to an integer.

APPENDIX III

Derivation of probe distance variation due to drum eccentricity.

Assume axis of rotation does not coincide with geometric center of the drum. To find variation of $R + a - r$ with time.



R = drum radius

a = eccentricity (distance from center of rotation to geometric center).

Eq. of circle:

$$R^2 = a^2 + r^2 - 2ra \cos(\theta - \pi/2)$$

$$r^2 = R^2 - a^2 + 2ra \sin\theta$$

$$r^2 - 2ra \sin\theta = R^2 - a^2$$

$$r^2 - 2ra \sin\theta + a^2 \sin^2\theta = R^2 - a^2 \sin^2\theta$$

$$(r - a \sin\theta)^2 = R^2 - a^2 \cos^2\theta$$

$$r - a \sin\theta = (R^2 - a^2 \cos^2\theta)^{1/2}$$

$$r_{max} = R + a$$

Let $\Delta r = R + a - r$

$$\Delta r = R + a - a \sin\theta - (R^2 - a^2 \cos^2\theta)^{1/2}$$

$R \gg a$, then $R^2 \gg a^2 \cos^2\theta$, and:

Therefore,

$$\Delta r = R + a(1 - \sin\theta) - R$$

$$\Delta r = a(1 - \sin\theta)$$

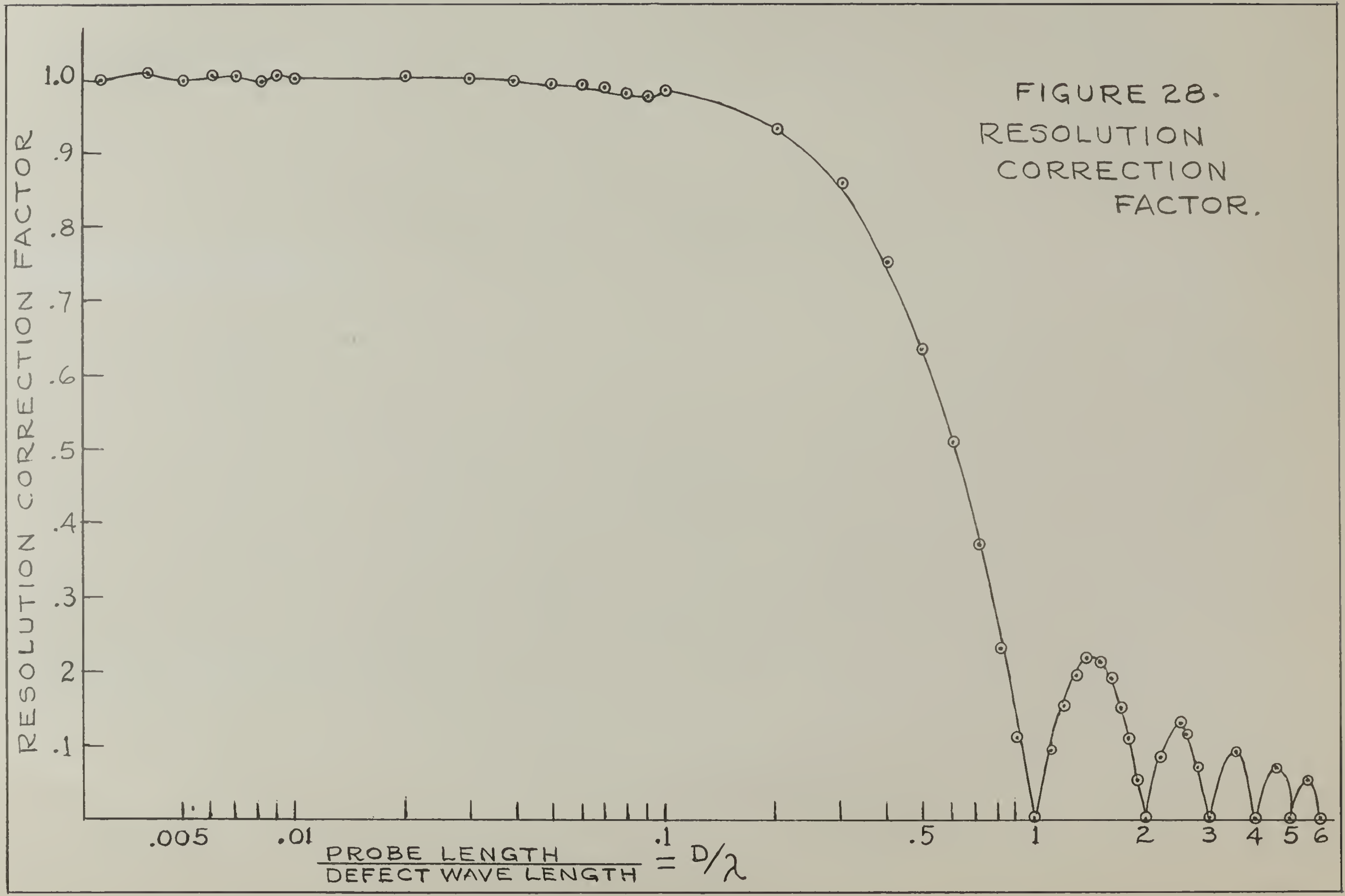


FIGURE 28. RESOLUTION CORRECTION FACTOR.

APR 1	BINDERY
MAY 5	RECAT
MAY 27	BINDERY
JUN 7	BINDERY
JUN 30	RECAT
JUL 6	DISPLAY

25288

Thesis Fossum
F65 A magnetic drum surface gauge.

JUL 6 DISPLAY

25288

Thesis Fossum
F65 A magnetic drum surface gauge.

thesF65
A magnetic drum surface gauge.
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